

UNIVERSITY
PENNSYLVANIA
LIBRARIES



**BIODETERIORATION OF STONE.
AN EVALUATION OF POSSIBLE TREATMENTS AND THEIR EFFECTS
WITH SPECIAL REFERENCE TO MARBLE STATUARY AT CLIVEDEN,
GERMANTOWN, PENNSYLVANIA**

KAREN JEAN FIX

A THESIS

in

Historic Preservation

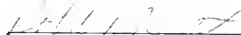
Presented to the Faculties of the University of Pennsylvania in
Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

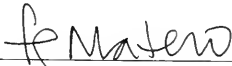
1997



Supervisor
A. Elena Charola, Ph.D.
Conservation Scientist



Reader
Robert Koestler, Ph.D.
Research Scientist



Graduate Group Chair
Frank G. Matero
Associate Professor of Architecture

Table of Contents

List of Figures iv

List of Tables v

Preface 1

Chapter 1: **Historical Background of Cliveden** 3

- 1.1 Introduction 3
- 1.2 The Site 3
- 1.3 The Statues 4
- 1.4 Historical References 9
- 1.5 Conclusions 12

Chapter 2: **Existing Conditions** 14

- 2.1 Introduction 14
- 2.2 Microclimatic Conditions Affecting the Statuary 14
- 2.3 Condition Survey 16
- 2.4 Summary 20

Chapter 3: **The Nature of Biological Growth** 21

- 3.1 Introduction 21
- 3.2 General Description 21
- 3.3 Biological Growth as Deterioration Mechanisms 24

Chapter 4: **Biocides** 28

- 4.1 What are the Options? 28
- 4.2 Biocides and Their Actions 29
- 4.3 Traditional Treatments 31
- 4.4 Barium Hydroxide 34
- 4.5 Relevant Legislation 35

Chapter 5: **Laboratory Evaluation of Surface Alterations
Induced by Chemical Cleaning** 37

- 5.1 Introduction 37
- 5.2 Experimental Program 37
- 5.3 Experimental Evaluation of Poultice Effectiveness 45
- 5.4 Experimental Results after First Poulticing 47
- 5.5 Poultice Reapplication 52
- 5.6 Experimental Results after Second Poulticing 52
- 5.7 Discussion 55

Chapter 6: **Laboratory Evaluation of Hygroscopicity
after Chemical Treatment** 58

- 6.1 Introduction 58
- 6.2 Experimental Program 58
- 6.3 Hygroscopicity Measurements 61
- 6.4 Removal of Retained Salts 64
- 6.5 Residual Hygroscopicity 66
- 6.6 Discussion 67

Chapter 7: **Discussion of Conclusions** 70

- 7.1 Summary 70
- 7.2 Laboratory Investigations 71

Bibliography 75

Appendixes 83

Appendix A: **Photos** 84

Appendix B: **Condition Surveys** 95

Appendix C: **Registered Products** 106

Appendix D: **Manufacturers** 126

Appendix E: **Micro-Drop Absorption and Surface Roughness Data** 133

Appendix F: **Hygroscopicity and Conductivity Data** 146

Appendix G: **Stones after Treatment - Photographs** 153

Index

List of Figures

- Figure 1. SEM Photo of Etched Marble. 27
- Figure 2. Thin-section of Marble, Sample F. 39
- Figure 3. Thin-section of Marble, Sample I. 40
- Figure 4. Thin-section of Sandstone, Sample K. 41
- Figure 5. Thin-section of Granite, Sample J. 41
- Figure 6. Stones before First Poulticing. 43
- Figure 7. Poulticed Marbles. 44
- Figure 8. Micro-Drop Absorption Time Comparisons of Marbles. 57
- Figure 9. Samples Immersed in Treatment Solutions. 60
- Figure 10. Dessicator Chamber. 60
- Figure 11. Hygroscopicity Test - Relative Weight Increase. 63
- Figure 12. Hygroscopicity Test - After Soaking. 68

List of Tables

- Table 1. Chemical Weathering Action by Biological Growth. 27
- Table 2. Summarized Surface Roughness Measurements. 49
- Table 3. Summarized Micro-Drop Measurements of Marble, First Poulticing. 50
- Table 4. Analysis of Variance for Micro-Drop Measurements - First Poulticing. 51
- Table 5. Summarized Micro-Drop Measurements of Marble, Second Poulticing. 53
- Table 6. Analysis of Variance for Micro-Drop Measurements - Second Poulticing. 54
- Table 7. Percent Moisture and Treatment Residue. 61
- Table 8. Weight Increase Due to Water Vapor Absorption. 62
- Table 9. Conductivity Measurements. 65
- Table 10. Percent Specific Conductivity. 65
- Table 11. Hygroscopicity Weights after Soaking in Water. 66

Preface

The proliferation of studies on the topic of biodeterioration of stone serve to show that this is a topic of which, while much is known, much remains to be explored. While the action of biological growth on stone is fairly well researched, the interaction of different species is not yet well understood. Methods of eradication, namely biocides, are well documented, a fact which is partly attributable to the imposed legislation regarding the use of chemical products within the United States. Nonetheless, given the adaptation of biological organisms to chemicals and the variety of stone types, accepted treatments require constant re-evaluation to affirm their continued effectiveness.

A study undertaken at the Robert Gordon University in Scotland (Urquhart et al. 1996) investigated the active lifespan of various biocides on sandstone. This research was prompted when it was found that past treatments were not long-lasting, with some subjects requiring reapplication in as little as four months. This was thought to be partially a function of the chemical used, but a Grant and Bravery (1981) study on limestone and sandstone tied biocide efficacy to the mineralogy of the stone. The sandstone performed comparatively poorer. Young, et al. (1995) proceeded to demonstrate that among sandstones, those containing illite clay are able to retain the biocide for a greater length of time, and thus perform better, than those containing kaolinite clay.

An extensive test was conducted in Germany (Krumbein and Gross 1992) using 24 biocides on 14 strains of biological growth on three mineralogically different sandstones. Their findings lend support to the results reported by Grant & Bravery and by the RGU

while additionally showing that none of the products was really able to eliminate the biological growth completely when used at recommended concentrations.

The focus on sandstones in these studies could be attributed to the fact that the majority of the research on biodeterioration is carried out in Europe, where it is the most widely used building stone. Many of the findings of these European studies, although expanding the overall knowledge base regarding chemical treatments, are of little use within the United States due to federal laws restricting the use of many of the recommended products.

A second area to be considered is that of the effects of chemical treatment on stone. Much of the current research focuses on methods of eradication of biological growth, focusing on the growth itself with only a cursory glance at the condition of the stone after treatment is carried out. Success is measured by a lack of microbial activity without apparent concern for damage or alteration of the substrate.

The exploration of these two issues - the use of chemicals to remove biological growth from stone, and the effect of the chemicals on the stone itself - was suggested after the condition assessment of the outdoor statuary of a historic Philadelphia home, Cliveden, was carried out. This group of eight marble statues, believed to date from the late 18th century, all host varying degrees and forms of biological growth. An evaluation of possible treatments was undertaken, with the results presented here. This investigation contributes to the body of literature currently available on the subject of biodeterioration of stone, with the hope that it will encourage additional studies by others.

Chapter 1: Historical Background of Cliveden

1.1 Introduction

Chief Justice Benjamin Chew married Elizabeth Oswald, niece of Joseph Turner, in 1757. Construction of their summer home, Cliveden, began in 1763 and ended in 1767. During the Revolutionary War, British troops advanced on Philadelphia and took control of the house. As part of a larger campaign to force the British back, the Battle of Germantown was fought, unsuccessfully, on October 4, 1777, on the grounds of Cliveden. The house, also known as Chew's Mansion, and outdoor statuary suffered measurable damage as a result.

With the exception of the years 1779-1798, when the property was sold to Blair McClenachan, Cliveden was owned continually by the Chew family until 1971 when it was acquired by the current owners, The National Trust for Historic Preservation. The house is now open to the public, Thursday through Sunday, for guided tours.

A number of reports¹ are held by the staff of Cliveden giving complete details on the history of the house, its construction, and its inhabitants; therefore, this information is not included here.

1.2 The Site

The property is situated on six acres in Germantown, Pennsylvania, about twenty minutes north of Philadelphia. This is an urban area and Germantown Avenue, which

¹ Historic Structures Report (1994) and Historic Landscape Report, Martin J. Rosenblum, R.A. and Associates.
Cliveden, The Chew Mansion in Germantown. (1993) Nancy E. Richards, Chief Researcher.
Various loose papers filed and categorized as "Cliveden History".

runs along the south end of the property, is heavily travelled by private cars and public transportation. Air pollution levels are high and the climate is varied, with high humidity and temperatures in the upper 80's during the summer and numerous snow days with temperatures below freezing during the winter.

The house sits near the eastern side of the property; a layout of the grounds is provided in Appendix A. The entrance to the property is from the north end where there is a small parking lot. A paved driveway runs from the parking lot along the west side of the house, where it branches into a circle in front of the house, and continues to an unused, locked gate at the center of the southern property line. The entire property is fenced with either chain-link or a stone wall. There is a pedestrian entrance along the west side. In the northwest corner of the property is the carriage house, with staff offices.

The grounds are flat and grassy with a number of old-growth trees throughout. A landscaping crew visits approximately once a week with mowers and other equipment.

1.3 The Statues

There are eight marble sculptures set throughout the property. These include two lions, two busts on pedestals, one standing figure, two standing headless figures, a small pedestal, and two larger pedestals - one of which still holds the base of an urn that is kept in a storage shed. There are also a number of fragmentary pieces: a male torso, a statue base with feet, and a small ball. Photos of all are provided in Appendix A.

1.3.1 The Lions.

Cliveden Accession Nos. NT 73.55.1(1) and NT 73.55.1(2). The two lions are located on either side of the top step of the front staircase, about 3 feet from the front door. The front of the body is south, the rear is north, with their heads turned towards each other. Lion No. 1 is on the west side of the step, Lion No. 2 is on the east side. The lions appear to be resting on their hind legs, with the front legs lifted up and resting on some sort of shield which faces south. This shield has wavy, curled edges, with a single curl looping down to the front of the base. The tail on Lion No. 1 lays across the top of its left proper leg and rests near the outside of its left proper foot. On Lion No. 2 it is the right proper leg and foot. Both have a curly mane which has substantially eroded, more so on the back of Lion No. 1. On both lions, there are areas throughout where the surface has eroded and the harder veins of the stone now appear raised above the surface.

1.3.2 Female Bust

Cliveden Accession No. NT 73.55.4(1). This figure sits at the southwest corner of the house. It is of a female from the waist up, without arms. The head faces proper left at an angle. Drapery reaches across her back and fastens at her right proper shoulder, then folds over. Her hair is long and pulled together at the nape of the neck, then drapes partially across the shoulders. The facial features are gone except for a hollowed area beneath the brows. The back side of the bust is a concave shell from the shoulders down. This piece rests centered on a pedestal. There is a 1/2" wide line of some sort of epoxy or mortar which appears to have been a repair, where the bust rests on the pedestal.

1.3.3 Male Bust

Cliveden Accession No. NT 73.55.4(2). This figure sits at the southeast corner of the house, with very little grass at its pedestal base. It is of a male from the waist up, without arms. The head faces proper right at an angle. There is drapery reaching across his back, fastening at his right proper chest, then folding over. His hair is shoulder-length. The facial features are gone except for a hollowed area beneath the brows. The back side of the bust is a concave shell from the shoulders down. This piece rests centered on a pedestal. There is a 1/2" wide line of some sort of epoxy or mortar, which appears to have been a repair, where the bust rests on the pedestal.

1.3.4 Standing Figure.

Cliveden Accession No. NT 73.55.3(2). This statue is located southwest of the house, just south of the driveway leading into the circle in front of the house. It is a woman with drapery along her left proper side in back, ending at her shoulder with a strap running across her chest to her right proper hip, where the drapery folds over. Both arms end approximately six inches below the shoulder. The head has been reattached at the lower neck; there is some question as to whether this head is actually original to this body. Facial features are completely gone, with only indentations where the eyes were and an angled slab where the lower face was. The shape and large size of this slab suggests it is the result of trauma or mechanical damage, rather than erosion. This piece has some sort of 'stump', resembling a tree trunk, to the side of one leg and ending at about knee height. All three of the standing pieces, as well as a fragment of a fourth, have this similarity in form suggesting they were carved as a set.

1.3.5 Standing Headless Male.

Cliveden Accession No. NT 73.55.3(1). This statue is located to the rear of the house. It is a male, with drapery held at its right proper hip by its right proper hand, folding across his lower torso in front and under his left proper armpit, then covering his entire back. It appears to drape over his right proper shoulder; there is a strap running across his chest from his left proper shoulder to his right proper hand. The left proper arm is lost at the shoulder; the right proper arm at about four inches below the shoulder, but the hand remains attached at his hip. The 'stump' ends directly behind this hand. There is no head or neck. The left proper leg is gone, with a slight remainder of the toes left at the base. It appears that the left leg crossed over the front of the right, bent and attached to the right at the knee, with the foot bent at the balls of the foot and facing perpendicular to the right proper foot. There is a chunk taken out of the calf of the right proper leg where the two legs met. At the junction of the right proper thigh and the 'stump' is a small patch of what looks like an epoxy repair, but it's not evident what the purpose was.

1.3.6 Standing Headless Female.

Cliveden Accession No. 73.55.3(3). This piece sits about 4 feet to the east of the previously described figure. It is a female figure, dressed in a cloth of two lengths and belted at the waist. The right proper arm is missing at about 2" below the shoulder; the left proper arm is gone at the shoulder and part of the back appears to be broken off. The big toes of both feet are broken off. The statue is headless, with just a few inches of neck area. There is evidence of a previous repair running the circumference of the

figure, about 3" below the belted waistline, as if the piece was broken in half and reattached. The 'stump' sits on her left proper side, ending mid-thigh.

1.3.7 Small Pedestal.

Cliveden Accession No. NT 73.55.6(1). This smaller pedestal sits in a tree-lined area to the west of the east dependency building.

1.3.8 Urn and Pedestal.

Cliveden Accession No. NT 73.55.2. The pedestal is in the front of the house within the grassy circle surrounded by the driveway. The square base of the round urn remains on the pedestal with a 1/2" wide hole in its center. The urn was broken off at its base and is being kept in a 3-sided shed at the rear of the property.

1.3.9 Large Pedestal.

Cliveden Accession No. NT 73.55.6(2). This piece is identical to that of the urn pedestal. It is located in the rear of the house, within a small grove of trees and shrubbery. It sits on soft, leafy ground and, due to the sinking of the south-facing side of the pedestal by several inches, the pedestal is leaning over. The northwest corners of the base and of the top surface are chipped off.

1.3.10 Torso.

Cliveden Accession No. NT 73.55.7. Investigation of this piece could not be accomplished with any accuracy due to its positioning between the lower branches of a tree and its ivy-covering, but it appears to be the upper torso of a male.

1.3.11 Base with Feet.

No Accession Number. This fragment consists of the base of a statue, about 4" of the 'stump' found on all the other standing figures, and the toe portion of both feet which are placed perpendicular to each other. The piece rests in a protected area behind the house.

1.3.12 Ball.

Cliveden Accession No. NT 73.55.5. This is a small gneiss ball that probably rested atop the small pedestal. It sits on the bare ground, in the open, also to the west of the east dependency building.

1.4 Historical References

Reference to outdoor statuary is found in family correspondence and manuscripts, in addition to historical photos and paintings, many of which are now kept by the Historical Society of Pennsylvania located in Philadelphia. Images of the Battle of Germantown portray the house with much of its statuary toppled and broken, though we can't be certain the existing pieces and those in the images were one and the same. Although the exact origin of the statuary cannot be pinpointed, much can be deduced from the aforementioned documentation.

A genealogy book kept by recent day Chew family members contains a short note next to the entry for Elizabeth Chew, noting that she was the niece (and heir) of Joseph Turner, who brought “marble statues & urns from Italy.”²

When Joseph Turner died in 1783 a second niece, Margaret Oswald (wife of Frederick Smyth), inherited his home called Wilton Plantation. An 1877 reference describes Wilton as having a superior garden with “Many statues of fine marble...” (Watson 1877, vol 2, p. 478). Sometime between Turner’s death and 1790, the plantation was sold to Henry Hill, Esq., who then rented it to William Rush, referred to as a city grazier³. A series of letters were exchanged between Henry Hill and Benjamin Chew referring to a group of marble statues at Wilton Plantation and their disposition upon acquisition of the property by Hill. Chew felt that they were part of the personal estate while Hill considered them a permanent fixture of the grounds. Margaret Oswald Smyth was of the opinion that the statues should be considered as part of the sale of the house “...especially as the things of that Sort given by my late Uncle to Mr and Mrs Chew went to the Purchaser of their house near Germantown”⁴ (this refers to the sale to Blair McClenachan in 1779). It is possible this is a reference to the two lions and/or the two busts.

Following his belief that the statuary were a part of the estate, Chew, as executor of the estate, took action to sell them. In his April 9, 1791 bill of sale to his nephew Edward Tilghman, who was also husband to his daughter Elizabeth, Chew lists “4 marble balls, 4

² Chew Genealogy Book, pg. 9, compiled by Anne S.P. Chew Barringer, Dec 1969, held at Cliveden.

³ Historical Society of Pennsylvania (HSP), Philadelphia, Library Company Manuscripts, lease from Henry Hill, Nov. 26, 1791.

marble pedestals, 4 large statues together with 4 marble pedestals"⁵. Further investigation is necessary to determine the disposition of the pieces after Tilghman received them, but it seems possible that, because he was Chew's son-in-law he may have brought the pieces to Cliveden. Consequently, the four large statues he purchased could be the three, plus fragments, that are currently at Cliveden, i.e., the two headless standing figures, the single standing figure, and the torso together with the base with feet.

In Chew's Receipt Book for the years 1770-1809,⁶ there is an entry for May 23, 1771, noting payment to Peter Biggs "for mending and cleaning 2 marble lyons..." which are, presumably, the two now placed on the top step at the front entrance.

No evidence has yet been found to indicate that the lions were obtained at the time of Cliveden's construction and it seems unlikely that they would need repair and cleaning after only 4-8 years (Cliveden's construction ended in 1767). In the same year as this cleaning/repair, Chew purchased a townhouse on South Third Street in Philadelphia which was known to have spacious gardens (Eberlein 1912). Perhaps the lions were in the gardens at this city residence and were brought to Cliveden during its construction. Further investigation into the chain of title and inventories of this Third Street residence, prior to Chew's acquisition, could possibly provide further evidence supporting this theory.

⁴ HSP, Chew Papers, Box # 248, "1791 Marble from Wilton" folder, April 15, 1792 letter.

⁵ HSP, Chew Papers, Box #248, Bill of Sale in "1791 Marble from Wilton" folder.

⁶ HSP, Chew Papers, Box #31.

No reference to the two busts have been found in written documentation. Because they were not mentioned in the bill of sale to Edward Tilghman, it seems certain that they were not acquired then. Therefore, they were either included as part of the earlier gift from Joseph Turner (a date for which has not been established) or were obtained in some other unknown manner.

1.5 Conclusions

Given Chew's wealth and position in society, it's unlikely any of the statuary were bought 'second-hand', although they could have been acquired as part of an inheritance. It would appear that the lions were brought to Cliveden at its construction or shortly thereafter, but they were not new at the time. They were either brought from the Third Street residence or from Wilton Plantation as a gift or inheritance from Joseph Turner. Chew's Receipt Book provides evidence that the lions were there in 1771.

Margaret Oswald Smyth's letter of 1791 provides evidence that there were marble statues at Cliveden by 1779, when it was sold to McClenachan, but it's not clear whether the letter is referring to the lions or something else. It is probable that the pedestals and the three standing figures were brought to Cliveden sometime after their purchase by Edward Tilghman in 1791 from the estate of Joseph Turner. The letters between Henry Hill and Benjamin Chew consistently refer to four large statues and pedestals. Counting the torso/fragment with feet, there are two men and two women standing figures, creating a symmetrical grouping. All three standing figures, and the feet fragment, have a similarity in form. All four of the pedestals have the same incised decoration across their face. All four pedestals also have the small metal posts at each corner of the top

surface; these could have been a part of the mounting supports used to attach the statue to the pedestal. The base of each of the standing figures measures less than 1" smaller than the top surface measurement of the pedestals, fitting neatly. All these points support the view that the four figures mentioned in the Chew letters were the same as those now on the property (inclusive of the torso and fragment with feet).

It hasn't been conclusively established that the statues referred to in the Chew genealogy, as having been brought from Italy by Joseph Turner, are the same as the aforementioned. However, there are enough correlating references to make that assumption.

Chapter 2: Existing Conditions

2.1 Introduction

Any number of natural or man-made processes can serve to ruin the aesthetic quality of outdoor statuary. Climate and general weather patterns, caretaking techniques, mechanical impact, even the quality of the stone are all possible contributing factors to deterioration. These can result in conditions such as cracking, sugaring, erosion, efflorescence, and biological infestation. The cause for the latter is the availability of moisture.

The immediate environment, or microclimate, of an outdoor statue can markedly contribute to its condition. Something even as small as a few extra hours of sunlight can make a difference. "...a more accurate analysis of the energy balance and resulting microclimate on the surface of the stone, where biological life occurs, shows that even small variations in the cloud cover, rainfall frequency or wind regime may cause very marked effects" (Camuffo 1991, p. 42). Hence, in those areas where a significant amount of moisture is found due to microclimatic conditions, it is more likely that greater amounts of biological growth, and its resultant biodeterioration, will be found.

2.2 Microclimatic Conditions Affecting the Statuary

A number of seemingly unrelated matters can play an important part in the proliferation of biological growth. Such things as surface inclination of the stone, pollution levels, shade patterns of the surrounding trees and shrubbery, and amount of direct sunlight all add up to create a microclimate within which biological growth can be cultivated or debased. "Many biodeterioration problems arise where harmful micro-environmental

conditions are created by particular architectural features; these can provide ecological niches, where the resultant floras, lichen or otherwise, promote biodeterioration.” (Seaward and Giacobini 1991).

Horizontal surfaces can serve to promote pooling or slow run-off of rainwater which means surface moisture is retained longer. The result is increased levels of moisture for more extensive periods of time, with an extra possibility of the water seeping beneath the surface and remaining there as ‘storage’ for algae and lichen.

Those parts of a stone which remain shaded for extended periods of time maintain a level of dampness favorable to microbial plant life, giving them an extended growing period with ready access to one of the necessary ingredients for sustenance - moisture. In addition, low levels of sunlight are favorable to heterotrophic organisms, which don't carry out photosynthesis and therefore don't require sunlight for viability, and allow them to take root and multiply. Conversely, where sunlight is prevalent, autotrophs are able to carry out growth-sustaining photosynthesis and are, therefore, more prolific, although the drying effect of the sun can reduce the amount of available moisture.

Increased pollution levels of recent years result in greater amounts of SO_x and NO_x particulates in the air. Placement near the sources of this pollution will obviously make marble statues more prone to pollutant deposition. Algal growth provides a bed upon which these deposits readily accumulate, providing nutrition for bacteria and its deteriorating mechanisms, and giving the surface area a blackened appearance. When this dark, discolored area is exposed to sunlight it can serve to retain the sun's heat,

increasing the stone's temperature and providing a more nurturing environment for biological growth.

An attempt to control the effects of microclimatic weathering was made at a rock art site in Canada (Young and Wainwright 1995) where an enclosure was built around the site. Cracking as a result of freeze/thaw cycles and prolific growths of blue-green algae were traced to the presence of moisture, which had increased over the years due to the shading of nearby trees. It was decided that controlling environmental factors was the most feasible solution, with laboratory testing of potential algicides undertaken as an alternative should the structure's protective nature fail.

In an outdoor environment there isn't much that can be done to control microclimate, but an understanding of its effect on the rate of biodeterioration can aid in determining a course of action.

2.3 Condition Survey

It is important to study the object's current condition to determine if treatment is appropriate. Examination of the statuary was performed in August 1996, and a graphical representation of their condition can be found in Appendix B. Narration and a description of microclimate conditions is included here for two of the pieces, the male and female bust, as representative examples of the group.

All of the statuary, except the lions, are in flat, grassy spots, facing south. There are no visible markings or inscriptions on any of the pieces. All pieces host some degree of

biological growth, mostly in the form of green algae. Examination after a day's rain show a temporary increase or swelling of this growth, with a bright green and slimy appearance. Exposure to sunlight serves to eliminate this effect. Those pieces not receiving sunlight exhibit blackening, which could be a staining from fungal secretions or biological growth which has dried out. The surface texture of all pieces is rough and granular, and examination with an 8X lupe shows that both the blackening and the green biological growth is intergranular. Dark black, fuzzy clusters of fungi were found mostly on horizontal surfaces, and appeared on all pieces except the female bust and the two lions. There is some degree of bird excrement or insect infestation on all of the statuary. The issue of 'loss', defined as the absence of original material, was not addressed in this condition survey because the original appearance of the pieces is not known. For instance, it is entirely possible that the headless standing figures were created without heads and/or arms. In those instances where it is obviously a loss, such as the left proper leg of the standing headless male, it shown in the Appendix as 'holes/dents/scratches'.

The male bust receives less than an hour of early morning sun exposure, on its northeast side, and less than an hour of afternoon sun across its face and chest. It is otherwise shaded. The house sits about 10' away to its northwest, the dependency building is to its north. Approximately 30' to the east are a continuous line of trees (except for a 10' gap directly across from the bust) marking the edge of the property. On the other side of these trees is Johnson Street, a well travelled 2-lane neighborhood street.

The drapery and concave shell are blackened with biological growth and the face and left proper shoulder are green algae-covered. The only areas free of growth are those areas receiving a small amount of sun exposure: the center of the chest, the right proper neck, and the lower 1/3 of the pedestal. The top of the head hosts clusters of black fungi, as do some of the folds of the drapery and the horizontal surface of the pedestal. There are soot deposits under the left proper jawline and hairline and a fine layer of soot all along the left proper side. There are areas throughout the bust where the surface has eroded and the harder veins of the stone now appear raised above the surface. The concave shell area is sugaring.

The top 2/3 of the vertical surfaces of the pedestal is covered in green algae. Some clusters of black fungi are found on the top horizontal surface and at the bottom base on the north and south sides. There are small patches of grey lichen on the upper portion of the north side of the pedestal. The west side of the pedestal is nearly clean, but there is a large patch of exfoliation on the upper half. It is possible that, because lichen are known to attach themselves deep within the stone and then dislodge the marble grains, there could also have been a lichen population on this side which has now removed the marble surface, and itself, in the process. Or, the loss may be due to a weak area in the stone itself, making it more susceptible to damage. The south side of the pedestal has 5-7 small, round, slight indentations placed close together - since this is the site of the Battle of Germantown it is likely that these are markings from bullets. There is soiling along the base of the pedestal, perhaps from rain hitting the soil and splashing back onto the marble.

The female bust is shaded until late morning, then receives full sun on the front surface. It is exposed to wind from all sides except the northeast which is blocked by the house, about 10' away. The back side of the bust, within the concave shell, shows minimal signs of sugaring, as does the lip of the pedestal and the top of the head. Approximately 40% of the front surface and nearly 90% of the back surface is green algae-covered (this piece shows no signs of the biological blackening). On some of the surfaces where there is no algae evident to the naked eye, the surface has a light orange tint. Although further investigation would be necessary to substantiate it, some scientists believe colored stains to be the result of the presence of biological growth. "The presence of algae and especially of cyanobacteria in and on top of marble surfaces generally leads to yellow and orange stains that are in part due to iron oxidation and in part to pigmentation by carotene and carotenoids" (Krumbein 1991, p. 443). There are areas throughout the bust where the surface has eroded and the harder veins of the stone now appear raised above the surface. There is a deep, cleaved crack along the left proper shoulder, running from front to back.

The east side of the pedestal has minimal algae while the other three sides are 2/3 covered. The north side of the pedestal shows signs of grey lichens growing on the upper 1/2 of the vertical surface. The pedestal's vertical surfaces have eroded, revealing the bedding plane (which appears as diagonal grooves). The lip of the horizontal surface of the pedestal shows the same erosion. All four corners of the pedestal's base are chipped, probably the result of physical trauma.

2.4 Summary

Because the male bust is mainly in the shade, the cyanobacteria and fungi have an ideal environment in which to develop. Those areas that receive sunlight become a habitat for green algae, which then, through their metabolic activities, provide nutrition for the bacteria.

While both sculptures receive a southern exposure and thus greater periods of sunlight, the male bust is shaded by surrounding trees while the female bust is out in the open. The latter is also more exposed to the drying forces of winds. Both these factors serve to hinder the biological population's ability to sustain growth, as evidenced by the lack of fungi clusters.

The male bust is located on the fringe of the property and in close proximity to the street. This exposure to automobile exhaust explains the soot deposits, where there are none on the female bust. The presence of algae, in those areas receiving sunlight, assists in the adherence of the particles to the surface.

The female bust experiences a microclimate of full sunlight and exposure to winds while the male bust is shaded, protected from wind, and in proximity to a city street with its accompanying soot and pollution. These two statues at Cliveden, presumably of the same marble but with significant differences in biological growth, clearly illustrate the point made by Urzi, Krumbein, and Pernice (Urzi et al. 1992) who demonstrated that microbial activity varies dependent upon microclimatic conditions.

Chapter 3: The Nature of Biological Growth

3.1 Introduction

All stone subjected to the elements of an outdoor environment will eventually suffer from deterioration, also identified as 'weathering', in one form or another. The causes are numerous: mechanical abrasion from wind, tree branches, debris, people; chemical alteration and surface deposits from rain and airborne particulates; structural damage due to incompatibilities in materials, freeze/thaw cycles, migration of salt deposits; and visual detracting, such as staining, from rainwash patterns. In many cases, stone subjected to one form of weathering then becomes more susceptible to additional forms. For example, a loss of substrate will increase surface area and roughness, creating a more ideal habitat for the introduction of biological growth and its resulting deterioration processes.

3.2 General Description

Due to their specific presence on the statuary at Cliveden, focus will be given to the following forms of biological growth: algae, bacteria, fungi, and lichen. All biological growth has limiting factors, boundaries outside of which they cannot survive. These include temperature, humidity, light, salinity and pH. Their nutrition requirements include phosphorous, nitrogen, potassium, calcium, sulfur and magnesium with lesser amounts of sodium, chlorine, manganese, iron, zinc, vanadium, molybdenum, boron, cobalt, copper, and silicon (Caneva et al. 1991).

3.2.1 Algae are autotrophic, sometimes called phototrophic, meaning they contain chlorophyll and are capable of the process of photosynthesis - producing their own food.

The predominant form of algae found on inorganic substrates is *Chlorophyta*, or green algae. Algae cells have a hygroscopic, mossy sheath which retains water and stores nutrients which may be used by other organisms as well, such as by heterotrophs. Algae prefer dampness and can be found particularly in areas where water run-off occurs, forming a conical green trail beneath the sides of vertical projections. As these microorganisms dry out, they turn black. Many times black deposits on stone are mistaken for pollution and soot deposits when they are actually algae which are no longer moist. To add to the confusion, algae can trap soot particles which then give the microorganism a darker appearance; it's thought that the hygroscopicity of the mossy sheaths contributes to this attachment of air-borne particles. Although the majority of algae keep to the stone's surface, some organisms insert cells deep into the stone's pores.

3.2.2 Bacteria. *Cyanophyta*, or cyanobacteria, are also autotrophic, possessing characteristics of both algae and bacteria. They produce oxygen as a waste product of photosynthesis, like algae, although they lack chloroplasts. They are one-celled organisms, like bacteria, but the majority do not travel by means of flagella as bacteria do. Their blue-green color is due to the presence of chlorophyll and phycocyanin and are thus sometimes referred to as blue-green algae. Like *Chlorophyta*, this microorganism is sometimes indistinguishable from pollution deposits.

There are a number of other forms of bacteria, such as nitrifying bacteria, which live in the form of a biofilm of a hygroscopic gel beneath the substrate surface and resist extremes in environmental conditions. Nitrifiers are divided into two entities: ammonia-

oxidizers and nitrite-oxidizers. *Ammonia-oxidizing* bacteria convert ammonia to nitrous acid (nitrite) which “directly dissolves the calcareous binding material” of marbles (Bock et al. 1987, p. 436), while *nitrite-oxidizers* convert nitrous acid to nitric acid (nitrate).

Sulfur-reducing bacteria are anaerobic and live within the pores of the stone. In what’s known as the sulfur cycle, they reduce sulfate to sulfide which then rises to the surface. Here, *sulfur-oxidizing* bacteria convert sulfide back to sulfate where it then reacts with the marble’s calcium minerals to produce gypsum.

3.2.3 Fungi are heterotrophic and lack chlorophyll, therefore they cannot manufacture their own food and are dependent upon available organic matter. They attach to the substrate surface by means of a hyphae, which is usually hidden beneath the surface, and appear as furry, dark spots of gray, green, black, or brown. Included under this category are molds, mildews, and mushrooms. Fungi are immobile and their propagation is dependent upon the release and transport of spores.

3.2.4 Lichen are a symbiosis of algae - either green or blue-green - and fungus, with the fungi component comprising the bulk of the organism. The algae component synthesizes nutrients, some of which are then absorbed by the fungus, while the fungal component absorbs water for the entire organism. Lichen are able to survive a wide range of environmental conditions due to their make-up; in severe cases they may merely go dormant rather than die out. These organisms can burrow up to several millimeters deep from the surface of the stone. They attach to the substrate surface by rhizines (or hyphae) or roots and show preference for either calcareous or siliceous

substrates. The lichen classification is based upon the fungal component, the mycobiont, rather than the algae, or phycobiont and they can take the form of projections (fruticose), encrustations (crustose), or leaf shapes (foliose), in various colors, such as yellow, green, gray, or brown.

3.3 Biological Growth as Deterioration Mechanisms

Each of these types of biological growth can inflict damage through either physical or chemical means. Physical weathering results from the mechanical action of the organism burrowing beneath the substrate surface and dislodging the mineral grain from its binding matrix. When moisture is retained in the organism's 'root' structure and freeze/thaw or wet/dry cycles occur, the ensuing expansion and contraction forces exacerbate this mechanical action. On the surface, deposits of biological growth can clog the stone's pores and prohibit the natural flow of water, thus contributing to any spalling or exfoliation of the surface.

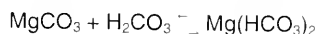
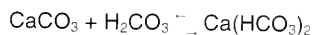
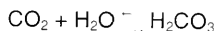
Plant roots carry a strong negative charge and are surrounded by a high concentration of positive ions which, typically, are hydrogen. As the plant root enters beneath the substrate surface, in a combination of mechanical and chemical weathering, the mineral cations are displaced by the hydrogen and subsequently absorbed by the root, (Keller and Frederickson 1952) causing a change in the mineral grain's chemical properties and subsequent mechanical damage. Examination of a biological population through energy-dispersive x-ray analysis (EDXRA) showed that calcium minerals can be proactively leached out of marble by the microorganism, rather than just being absorbed as a byproduct of acid leaching or a dislodging action (Bech-Anderson 1984).

Fungi sometimes burrow deep within the stone (becoming endolithic), either travelling through the capillaries or creating their own paths, and attacking the interstices of the stone. Koestler, et al, found in their investigation of the deterioration of calcitic and dolomitic stones (Koestler et al. 1992) that cultured fungal hyphae penetrated into the subject crystals by 1mm in only five weeks.

Lichen attach to the stone with their hyphae or rhizines and create crater-like depressions and blistering in the uppermost layers of the stone surface. Cyanobacteria don't have the physiological capacity to mechanically attack stone directly, although the damage they invoke through chemical weathering may result in powdering and exfoliation of the substrate.

Chemical weathering results from attack by acids and/or complexing agents released by microorganisms. These acids and chelating agents can then react with the substrate to form soluble salts.

Autotrophics (algae, lichen, bacteria) produce *inorganic acids*, such as sulphuric and nitric. The CO₂ of plant respiration reacts with water to form carbonic acid, which, then reacting with the relatively insoluble calcium and/or magnesium carbonates found in marbles and dolomites, forms soluble calcium and magnesium bicarbonates.



Heterotrophics (fungi, lichen) produce enzymes which decompose organic substances (including the substrate material) for nutrients and in the process produce *organic acids* such as citric, lactic, succinic, and α -ketoglutaric as a byproduct. These organic acids can both dissolve calcareous stones as described above and coordinate with the metal ions of the stone's mineral through chelate formation. The strength of this chelating action determines the degree of deterioration produced. The mineral damage incurred by this chelating action includes the extraction of cations, such as iron, potassium, and aluminum; alteration to an amorphous structure; and etching out of lamellar intergrowths (Jones et al. 1987, p. 130). The resulting chelate will then leach out and either wash away (if it is surrounded by hydrophylic groups and is, thus, soluble) or it will precipitate within the stone's capillaries or on the stone surface (if it dries out, or if it is surrounded by hydrophobic groups and is, thus, insoluble).

A scanning electron microscopy (SEM) photo (following page) shows the type of etching that can occur as a result of chemical weathering from biological growth.

The formation of salts (Table 1, following) causes additional damage to the stone. Those salts that remain on the surface (efflorescence) are not harmful so much as unsightly. However, these may migrate to the interior of the stone and recrystallize as subflorescence. The resultant mechanical pressures can lead to spalling.

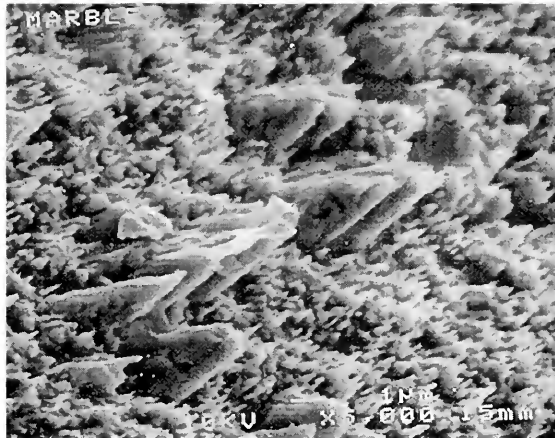


Figure 1. SEM Photo of Etched Marble.

A synopsis of the nature of chemical weathering is shown below, in Table 1.

	Biogenic Acid Produced	Elements Affected/ Geochemical Activity
Algae	Aliphatic dicarboxylic, Hydroxy, Ketonic, and Uronic acids	[Acid attack of calcareous material] Si, Al, Fe, Mn, Mg, Ca, K, Na, etc./ Dissolution of minerals by chelate formation
Bacteria	H ₂ SO ₄ , HNO ₃ , HNO ₂ , ∞ -KGA, Pyruvic, Citric, Lactic and Succinic acids	[Acid attack of calcareous material] Fe, Ca, Mg, S, N, Si, etc./ Oxidation of Fe, NO ₃ , S and HN ₃ , Dissolution of minerals by chelate formation
Fungi	Aliphatic, Carboxylic, hydroxy, Ketonic, Aldonic, and Inorganic acid	[Acid attack of calcareous material] Si, Al, Fe, Mg, Ca, etc./ Dissolution of minerals by chelate formation
Lichens	Aliphatic Carboxylic, hydroxy acids and Aromatic phenolic acids	[Acid attack of calcareous material] K, Na, Mg, Ca, Si, etc./ Dissolution of minerals by chelate formation

Table 1. Chemical Weathering Action by Biological Growth⁷
[with additional comments by author]

⁷ Saxena et al. 1991, p. 253.

Chapter 4: Biocides

4.1 What are the Options?

Biological growth may initially only be an aesthetic problem, discoloring the stone and obstructing the details of the stone's carving. However, if left unchecked it can develop into a more serious problem. Biological growth attack the stone's surface, dislodging minerals and increasing surface area and roughness. This in turn enhances any chemical dissolution and may create an environment conducive to further attack by providing a foothold for new populations. Careful consideration should be given to the issue of its control before the integrity of the stone is left completely undermined.

There are two approaches to the removal of biological growth: control and cleaning. *Control* is achieved through the use of pesticides, also known as biocides, which in principle kill the growth completely. Included under this category is "...any agent used to kill or control undesired insects, weeds, rodents, fungi, bacteria, or other organisms" (EPA 1991, p.2). Inappropriate biocides would include any that could alter the structure or color of the stone, leave deposits, or have an exceedingly short life. *Cleaning* is the surficial removal of the growth and any resulting soiling substance. While giving the appearance of eliminating all visible plant forms, it is temporary by nature because spores and deeper growth can remain under the surface and rapidly re-infest the object. Some cleaning methods, such as bleaching, kill the visible growth and act on the soiling substances, giving the appearance of being clean without actually destroying all of the biological material.

There are basically three methods by which to accomplish cleaning or control: mechanical, water-based or chemical.

Mechanical removal is not recommended for the statuary at Cliveden as it requires a certain level of abrasion to the surface. Even a delicate method such as low pressure grit blasting (using soft materials such as walnut shells or glass beads) may not be effective for these pieces because even the minimum pressure required to remove the growth would be strong enough to abrade the already deteriorating surface.

Although a *water-based* method of cleaning would seem to be the less harmful of the three, it is not necessarily effective against biological growth. Low pressure water spray can be effective, but it could actually push the growth deeper into the surface of the stone making it appear clean when it is not. Use of water with a non-wire brush is a possibility, however spores could remain beneath the surface with the ability to regenerate.

Chemical methods are used to eliminate the growth through toxicity. A chemical treatment can be designed that is minimally harmful to the stone while accomplishing the goal of eliminating the plant life, thus becoming the most appropriate choice in this case.

4.2 Biocides and Their Actions

The types of products typically used on stone masonry can include herbicides, fungicides, bactericides, or algacides. Although each was designed for eradication of a

specific species of organism, a process known as selectivity, many times they are effective on others.

While the following concepts are agriculturally-directed, understanding them can aid the conservator in selecting appropriate products for non-agricultural applications.

Herbicides can be divided into groups based upon chemical affinity: aliphatics, amides, benzoics, bipyridiliums, carbamates, dinitroanilines, diphenyl ethers, nitriles, phenoxys, thiocarbamates, triazines, uracils, ureas, and unclassifieds (Ashton 1981, p. 10). A simplified approach, more relevant to conservation, is taken by Caneva, Nugari, and Salvadori (1991, p. 142) who divide herbicides into inorganics, urea derivatives, diazines, triazines, piridines, imidazolinones, phosphoorganic compounds, and mixtures. Most products work by inhibiting growth, blocking photosynthesis, or inducing loss of integrity of the cell membranes and chloroplasts.

Herbicide application can be categorized as either soil or foliar. Soil applications can be either *residual*, where the killing action persists for months or years, or *fumigants*, which usually act subterraneously and have a short life. Foliar applications are either *contact*, killing that part with which they come in contact, or *translocated*, moving within the plant body.

Fungicides, bactericides, and algicides can be grouped together and broken down into inorganics, organometallic compounds, phenolic compounds and derivatives, quaternary ammonium compounds, and mixtures (Caneva, Nugari, and Salvadori 1991, p. 134).

These can be subdivided into three categories. *Protectants* are usually foliar and are applied, as the name implies, to protect the healthy foliage from possible attack, while *eradicants* rid the plant of an existing pest. *Systemics*, or chemotherapeutants, are applied either foliarly or via soil and are translocated within the plant protecting those areas that would normally be missed (e.g., the underside of the leaf).

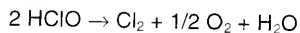
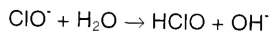
A short history of the development and use of insecticides is provided by Cook (1989), although this publication was written at the same time that current regulation regarding insecticide use in the United States was being revised and some products may no longer be available for use.

4.3 Traditional Treatments

There are a number of chemicals available today that, although not designed for that use, will elicit the same effect as commercial agriculturally-marketed biocides.

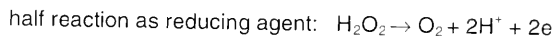
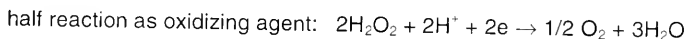
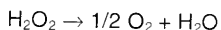
One of the traditional methods for cleaning biological growth from objects such as textiles and paper has been through bleaching. One form of bleaching uses the process of oxidation to break apart covalently bonded compounds. (A second form works by reduction.) When oxidation occurs, chromophores, which allow a substance to appear colored, are either broken apart and the object (e.g., dirt, stains, biological growth) no longer appears colored, or their solubility is increased so that the substance can be washed away.

Hypochlorites were used for textile bleaching in the 18th century and industrial paper bleaching until the early 20th century. Sodium hypochlorite, NaOCl, is commonly known as liquid bleach and calcium hypochlorite, CaCl_2O_2 , as dry, powdered bleach. Their bleaching ability is due to the formation of the oxidizing agent, hypochlorous acid. The released chlorine and oxygen act as a disinfectant, destroying bacteria.



The use of hypochlorites is expected to decrease in the future as they generate chloroform, a government-regulated toxic substance (Kirk-Othmer 1992, pg. 304).

A third type of bleach, hydrogen peroxide, H_2O_2 , acts as both an oxidizing and reducing agent, called an auto-oxidant. It is a weak acid and its bleaching action stems from the oxidation ability of the peroxide anion by the release of oxygen.



Although the use of bleaching agents on fabrics and paper is well documented (Tendulkar 1993; Hoffman and Banik 1991), studies of their use on stone are less prevalent. At Nicolas Copernicus University in Poland, a study (Leznicka et al. 1988) was conducted using bleaching agents - chloramine T, hydrogen peroxide, and calcium hypochlorite - with the latter providing the best results for both sandstone and limestone.

A paper by Tudor, Matero, and Koestler (1990) also investigates the use of calcium hypochlorite on stone.

In another study, a special formula was designed for the cleaning of stains and discolorations caused by biological growth, based upon the bleaching action of sodium hydrosulfite (Barov 1987). The effectiveness of this formula was then compared against the actions of traditional bleaching products such as hydrogen peroxide and calcium hypochlorite. Although the solution worked effectively in removing the stains, the author prefaces the results with a recommendation that a biocide be used prior to application in order to kill the growth.

An attempt at removing biological growth from marble using sodium hypochlorite and hydrogen peroxide, along with three mainstream biocides, is presented by Nugari, D'Urbano and Salvadori (1993). Their measurement of success was the absence of fluorescence when the stone was viewed under UV light, indicating a lack of chlorophyll which should be present if live bodies of algae were found.

These three products - sodium hypochlorite, calcium hypochlorite, and hydrogen peroxide - have seen much use in the areas of paper and textile conservation, with a cross-over into other areas. Although they were not originally designed for that purpose, their use as biocidal agents has become widespread within the conservation community.

4.4 Barium Hydroxide

The last alternative to be discussed, barium hydroxide, $\text{Ba}(\text{OH})_2$, is an alkaline compound that has received attention in the past for its use as a consolidant. When Lewin designed his treatment (1971) his theory was that the barium in barium hydroxide would replace some of the calcium in the calcium carbonate, giving rise to barium carbonate. The addition of urea to the solution causes the production of new barium carbonate crystals and gives the final precipitate a white color. "The urea slowly undergoes hydrolysis producing ammonia and carbon dioxide. The liberated ammonia and carbon dioxide dissolves in the water forming ammonium carbonate which raises the pH of the solution. When a certain pH is reached, barium hydroxide reacts with the carbonate ion and barium carbonate is precipitated." (Clifton 1980, p. 20) These new grains of barium carbonate then fuse with the grains produced through the reaction with calcium carbonate and restore the stone's integrity. After treatment, sulfur oxides found in the atmosphere react with the surface barium and form barium sulfate. Barium sulfate is a much more stable and insoluble mineral than the gypsum that would otherwise have formed, thus giving the sculpture protection against weathering.

The treatment is meant to be applied through immersion into a hot solution; where this is not possible the solution is applied at ambient temperatures and left on the object, and kept wet, for a number of weeks. The addition of glycerin to the solution serves two purposes: 1) to keep it moist to allow the recrystallization process to take place to its fullest potential and, 2) to increase the solubility of the barium hydroxide, thus making more Ba^{++} available for reaction and allowing it to penetrate deep into the stone. If the

solution remains only near the outer surface, it can leave the stone prone to spalling or exfoliation.

4.5 Relevant Legislation

A 1947 law, the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) was amended in 1988 to reflect the need for closer administration of pesticide regulation by the Environmental Protection Agency (EPA). Registration of pesticide products had always been required under FIFRA, but as scientific knowledge grew and products became more sophisticated, authorities recognized a need to impose greater regulatory authority over the registration process to ensure public safety and reduce environmental threats.

It is illegal in the United States to use or sell for use any pesticide product unless it is registered under FIFRA. Although there are tens of thousands of pesticide products registered for use, registration is based upon the approximately one thousand *active ingredients* contained within these products. The active ingredient is that part of the product which acts to kill the organism.

Reregistration is required for those pesticides which were already in use at the time of the 1988 Amendment. All available test data, and any additional data required to meet new standards, is submitted to EPA for review. Upon reregistration, a Reregistration Eligibility Document (RED) is issued. Although, under the 1988 amendment, complete reregistration of all existing pesticide products was to have been completed by 1997, this is not the case.

The manufacturer of a *new* pesticide product is required to perform a series of specific tests based upon the proposed category of use. This test data is then reviewed and evaluated for potential risks, whereupon registration is either granted or denied.

To support this registration effort, fees are levied against manufacturers: a maintenance fee, per product, to cover the EPA costs of administering the registration process, and, additionally, each active ingredient carries a fee. Because many manufacturers' products use the same active ingredients, fees are split among the registrants based upon their market share of that active ingredient.

A number of industry surveys have been conducted in an attempt to compile a list of pesticide products available for use, among them a 1996 report out of Robert Gordon University (Urquhart 1996) and a 1983 survey by Allsopp and Allsopp (1983). Unfortunately, the 1983 survey was conducted before implementation of current EPA regulations and many of the products listed are no longer available. The Robert Gordon University report does reflect current products, however the majority are available for use only in the United Kingdom, again, due to EPA regulations.

Appendix C provides a list of current EPA registered, or reregistered, products that fall under the categories of herbicides, fungicides, algacides, or bactericides. Also included are the addresses and Internet web sites for as many manufacturers as possible, in Appendix D. These lists are not all-inclusive; for example, they reflect only U.S. manufacturers.

Chapter 5: Laboratory Evaluation of

Substrate Alterations Induced by Chemical Cleaning

5.1 Introduction

Before making the decision to chemically treat any work of art, thought should be given to how the treatment might alter the original appearance and/or affect the material. A paper put forth by Nugari, Pallecchi, and Pinna (1993) stressed the importance of evaluating the effects of biocides upon stone works of art. They state that while numerous studies of the effectiveness of biocides have been conducted, little investigation has been directed into the resultant condition of the stone surface. By applying biocides, then measuring water absorption and chromatic changes, and observing stone alterations through SEM, the authors contribute to that area of investigation.

5.2 Experimental Program

A plan was designed to investigate the effects of a selection of bleaching agents and/or whitening agents when used for removal of biogrowth and cleaning of stone. The incorporation of consolidation action was an added benefit in choosing barium hydroxide (a whitening agent) as one of the chemicals to be investigated.

The treatments were evaluated by visual examination, surface roughness measurements, and water drop absorption time.

5.2.1 Sample Selection

Four pieces of marble and one each of sandstone and granite, all weathered and with significant biological growth, were obtained from a collection of gravestone remnants from Woodlands Cemetery in Philadelphia.

The marbles were designated as stones E, F, and I, sandstone as stone K and granite stone J. One piece of marble (stone G) was eliminated from the test after poulticing, when it was determined to be too difficult to obtain accurate roughness or water absorption measurements due to its shape and extreme roughness.

Stone F is in the best condition and is the most cohesive of the marbles. It is a block of stone with a fairly level face. Stone E is arched and appears to be the top portion of a gravestone. The top surface is carved smooth but has eroded in some areas to create cracking, crevices, and rough spots, particularly along the outside edges. Stone I is columnar with a large beaded edge. The surface is extremely eroded and exhibits grain loss through sugaring. The rounded shape of stones E and I proved to be a small problem in successful application of the poultices, but even more so in the subsequent attainment of surface measurements.

Stone K, the sandstone, is slightly rounded and has an uneven contour. It does not appear to have a finished surface. The granite, stone J, is a rectangular shape with one half of its length smooth and the other half rough. It is probably the base of a gravestone which has broken off at the rough area.

5.2.1.1 Characterization of Stones through Thin-Section Microscopy

Thin sections were made for each stone and examined under a Nikon Optiphot 2-POL polarizing microscope, at various magnifications. All three marbles stained positively for calcite.

Stone F is pure calcite, with a compact, equigranular crystalline structure. No other mineral was found to be present with the exception of a few dolomite crystals. There is a high degree of lamellar twinning found, in one or two directions. This granoblastic stone exhibits a polygonal texture, where the majority of the grains are similar in size and five- or six-sided with three grains intersecting at a single point. The process called annealing produces an increase in grain size along with this texture. As smaller grains are subjected to high temperatures, they dissolve and their chemical components are taken up by the larger grains. The lack of elongation in the crystals indicates only a moderate amount of metamorphic pressure, which is conducive to annealing.

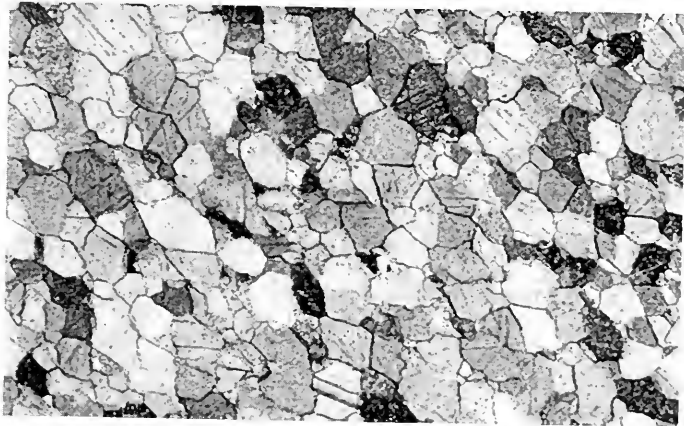


Figure 2. Thin-section of marble, sample F, at 50X magnification. Note the equigranular crystalline structure of this annealed marble of nearly pure calcite; many crystals exhibit twinning.

Stone E and Stone I are very similar in character. They are both formed of calcite along with numerous quartz deposits, both in small drops and along grain boundaries traversing the entire length of the thin section. Most grains have lamellar twinning in one direction. Grain size is varied and angular, with stone I exhibiting a greater angularity. There is a definite elongation of all grains, in one direction, evidence of metamorphic compression. One or two grains of dolomite are present.

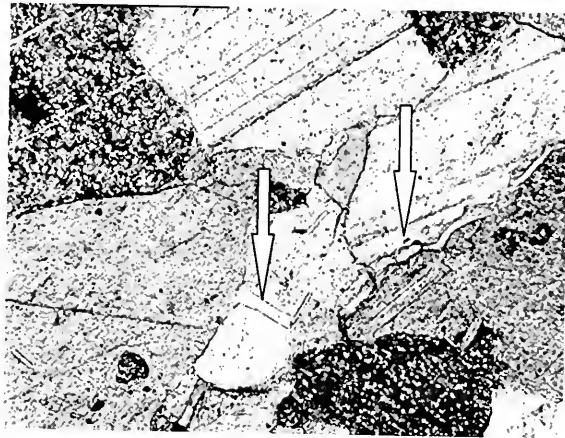


Figure 3. Thin-section of marble, sample I, at 100X magnification. This stone has numerous quartz deposits (at the arrow) and a few grains of dolomite. Grain size is varied and angular, with a definite elongation of all grains in one direction, evidence of metamorphic compression.

The sandstone, stone K, is classified as a quartz arenite due to its high quartz content. Small amounts of biotite and muscovite flakes are present, along with iron oxides and a few deposits of hematite. While many of the quartz grains are polycrystalline, very few are detrital - a characteristic common among sandstones. It is a well-sorted sample with very little fine-grained matrix.

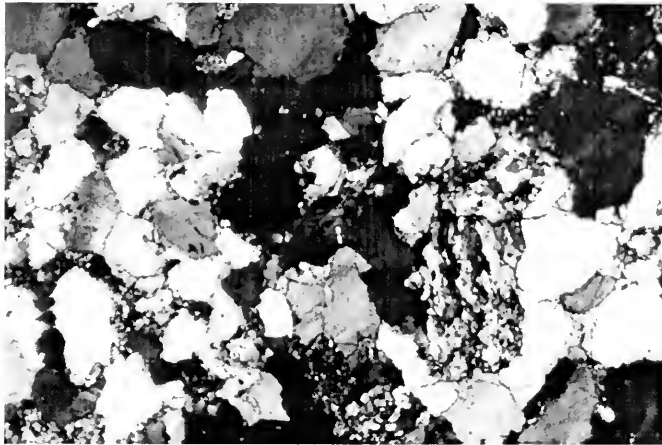


Figure 4. Thin-section of sandstone, sample K, at 50X magnification. Its high quartz content, many of which are polycrystalline, classifies this stone as a quartz arenite. Its composition includes small amounts of mica along with iron oxides.

The granite, stone J, is a coarse-grained biotite granite with deposits of quartz (some polycrystalline) and feldspars. Many of the feldspar grains exhibit perthitic texture, an intergrowth of plagioclase and potassic feldspars that occurs during cooling.

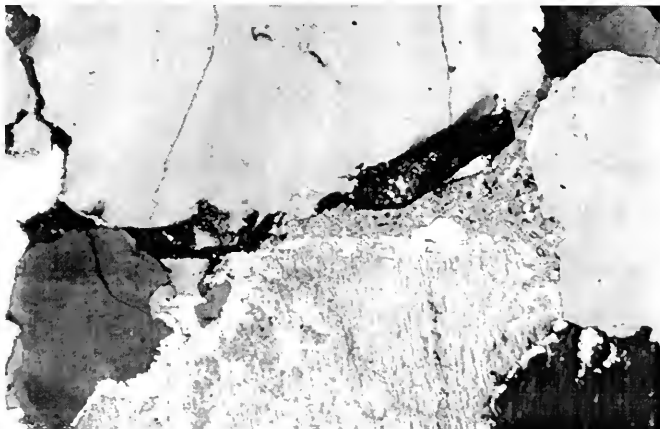


Figure 5. Thin-section of granite, sample J, at 50X magnification. This stone is a biotite granite with quartz and feldspar deposits. Many of the feldspar grains exhibit perthitic texture.

5.2.2 Materials

5.2.2.1 Poultice Materials

A variety of poultice materials, including paper pulp, pressed paper, cotton, kaolin clay, fuller's earth, and a 50/50 mix of fuller's earth and kaolin clay, were mixed with deionized water and applied to marble samples to ascertain the best choice for this trial. It was decided to eliminate the clay poultices, to preclude the possibility of leaving a residue in the stone pores due to the rough surface. Among the others, the paper pulp seemed to provide the greatest pliancy and cover capabilities. This material was consequently chosen for preparing the poultice.

5.2.2.2 Active Ingredients

The four products tested were used in the following concentrations:

33% w/v $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$ (barium hydroxide octahydrate)

7% v/v NaOCl (sodium hypochlorite, 13% active chlorine)

3% w/v CaCl_2O_2 (calcium hypochlorite)

30% v/v H_2O_2 (hydrogen peroxide; commercially available at this concentration)

The barium hydroxide solution was prepared by heating 500mL of water to boiling, adding 250g of solute and 200mL of glycerin, then removing from the heat. The addition of glycerin serves to increase the solubility of the $\text{Ba}(\text{OH})_2$ through complexation of the Ba^{++} ion. The solution was then filtered through a Whatman #1 filter paper to eliminate any BaCO_3 formed during preparation, and was ready to for use in the poultice once cool.

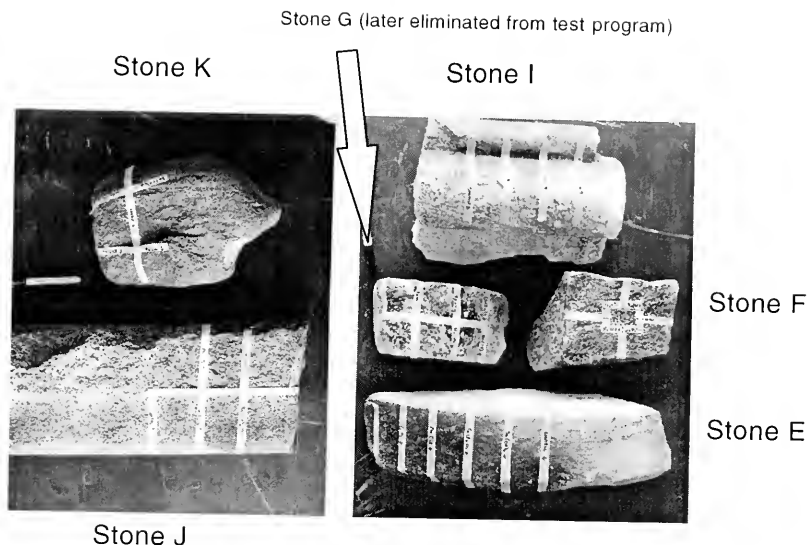


Figure 6. Stones before first poulticing. Each treatment area was marked off with masking tape and labelled appropriately.

5.2.3 Poultice Application

Five areas were marked on each stone; one for each solution plus one for a control using deionized water. A sheet of Japanese tissue paper was placed across each marked area and moistened with a paint brush. A poultice of paper pulp was mixed for each solution and placed on the appropriately marked area.

The hypochlorite solutions exhibited a strong reaction with the paper pulp; the calcium hypochlorite poultice, in particular, began bubbling, but both hypochlorite poultices lost their cohesiveness and began to spill over into the other treatment areas. Tongue depressors were placed around the poultice area to dam it up and prevent further

spillage. Once the poultices were applied and somewhat stable, they were covered with plastic wrap, sealed loosely, and left for 24 hours.

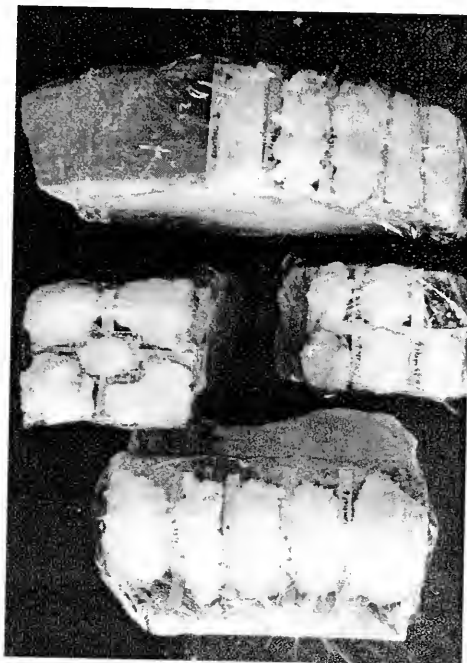


Figure 7. Poulticed Marbles.

The hydrogen peroxide poultice showed no visible reaction and stayed in place nicely.

The barium hydroxide solution required high levels of solution to make the poultice the correct consistency, although the paper pulp didn't seem to retain the solution, i.e., it dripped. When applied to the stone, it lay in clumps.

None of the poultices actually dried out. At the end of 24 hours, the plastic wrap was removed and the poultices lightly sponged off. The tissue paper had disintegrated into shreds for all treatment areas and was difficult to remove. The stones were left to air dry for several hours so the tissue paper could regain some coherence and be more easily removed. The surface was washed free of residues of poulticing materials and any loose biological growth by gently brushing with a natural bristle brush and deionized water. All treatment areas exhibited some diminishment of visible biological growth, although not a complete removal.

5.3 Experimental Evaluation of Poultice Effectiveness

Changes introduced by the above cleaning procedure were evaluated by visual examination and by measuring surface roughness and water absorption. Surface profile measurements were taken on all stones with a Surtronic 10R_a profilometer. Micro-drop water absorption was measured using a modification of RILEM Test I18.b for Water Absorption. These measurements were taken on marbles only since this stone type is the focus of this investigation. Both methods are known to give a wide dispersion in data. Hence, at least fifteen individual measurements were taken for each property measured and for each area considered. In total, 585 measurements were taken for the marble samples, 76 for the sandstone, and 57 for the granite. This amount of data was sufficient (see Appendix E) to be able to apply statistical analysis to determine with a given confidence level if the chemical cleaning had altered the stone surface.

5.3.1 Visual Examination

The stones were examined under natural light to ascertain with the naked eye if any color changes were evident and if substantial elimination of biological growth could be confirmed at a macroscopic level.

5.3.2 Surface Roughness Measurements

Surface texture is defined as the repetitive or random deviation from the nominal surface that forms the three dimensional topography of the surface (Veeco 1997). The irregularities in this texture can be measured with a stylus, as surface *roughness*. The data collected is called an arithmetic-average roughness height, or Roughness Average (R_a), and signifies the average deviation from the straight line.

A hand-held profilometer capable of measuring 0.1μ - 40μ was used to record surface roughness at 19 randomly selected spots within each of the four treated areas, plus the control area. The profilometer was recalibrated after every 3-4 readings to ensure accuracy.

One of the treated areas (NaOCl) within the sandstone was too sloped to allow use of the profilometer and two areas (NaOCl, H_2O_2) of the granite were too rough to produce accurate readings; these areas were disregarded for this test. Measurements above 30.5μ were automatically flagged by the device; this occurred 20 times for the marbles, 3 times for the sandstone, and 4 times for the granite. In most cases these readings were dropped, along with the lowest readings, leaving a total of 15 readings for each treated area.

5.3.3 Micro-drop Absorption Test

A burette was filled with deionized water and clamped into place at approximately 5cm above the surface area to be tested. A single drop of water was released onto the surface and its complete absorption into the stone was timed with a stopwatch. The burette was then moved to a new, randomly selected spot within the same treated area. Because of the small surface area, the procedure was paused after every three to four measurements to allow the stone to dry out.

This operation was repeated fifteen times for each treated area, plus the control area. An average drop weight of 2.17g was obtained by weighing 20 drops in a beaker. Given the density of water at 20°C of 0.9985g/cm³, the volume of each drop is 2.17 g/cm³.

5.4 Experimental Results after First Poulticing

5.4.1 Visual Examination

With the exception of the sandstone, all oxidizing treatments appeared to eliminate the growth of algae from all stones on those surface areas which were slightly raised; recessed areas still retained a minimal amount of biological growth. Although the sandstone appeared to have no remaining biological growth in any treatment area, these treatment solutions resulted in an extreme lightening of the stone's color and would preclude their use as cleaning agents.

The barium hydroxide treatment resulted in a brown discoloring on all stones. This is due to the extermination, although not the removal, of green algae which has

subsequently turned brown. Appendix G contains color photos of each of the stones after the first poulticing treatment.

5.4.2 Surface Roughness

Surface profile measurements were taken of all five stones, with some areas of the sandstone and granite disregarded due to small surface area or extreme roughness, as previously explained. Data was averaged and the standard deviation was calculated. All data is detailed in Appendix E. The F Test was then applied, comparing control areas to treated areas. The value obtained was compared to F values taken from statistical tables at 14 degrees of freedom (since there were 15 measurements taken) and a 95% confidence level. This data is summarized in Table 2. Except for stone F, treated with hydrogen peroxide, no significant difference can be established. Even the significant difference of this stone's particular treatment area is small enough not to be considered valid at this confidence level.

	CaCl ₂ O ₂	Ba(OH) ₂	NaOCl	H ₂ O ₂	Control
Stone E - marble					
Average	21.77	22.25	21.56	17.03	19.18
Std Dev	4.75	4.32	6.86	8.24	5.82
Variance	22.574	18.671	47.078	67.952	33.840
Calculated F	1.499	1.812	1.391	2.008	N/A
Stone F - marble					
Average	14.78	16.95	12.36	19.49	19.57
Std Dev	6.47	5.88	8.70	4.48	7.81
Variance	41.923	34.578	75.711	20.105	60.924
Calculated F	1.453	1.762	1.243	3.030	N/A
Stone I - marble					
Average	20.80	19.12	19.82	18.87	19.85
Std Dev	6.45	6.37	5.31	6.03	4.31
Variance	41.660	40.527	28.199	36.388	18.538
Calculated F	2.246	2.186	1.521	1.963	N/A
Stone J - granite					
Average	19.55	16.43	N/A*	N/A*	18.89
Std Dev	4.38	4.58			5.38
Variance	19.204	20.941			28.944
Calculated F	1.507	1.382			N/A
Stone K - sandstone					
Average	16.81	13.37	N/A*	17.51	15.73
Std Dev	6.49	6.78		6.52	4.96
Variance	42.108	45.959		42.550	24.607
Calculated F	1.711	1.868		1.729	N/A

Table 2. Summarized Surface Roughness Measurements. *F Values are calculated and compared to the tabulated F Value of 2.40 for 14 degrees of freedom, at a 95% Confidence Level. R_a values are in microns.*

* Surface measurements for Stone J (granite) and Stone K (sandstone) were not taken for all treatment areas due to irregularities or small surface area.

5.4.3 Micro-Drop Absorption Time

Micro-drop absorption time measurements were performed on the three marbles only, as this stone type is the primary focus of the study. Data was averaged and the standard deviation was calculated. All data is given in Appendix E. The F Test was then applied, comparing control areas to treated areas. The tabulated F value of 2.40, at a 95% confidence level using 14 degrees of freedom (since 15 measurements had been made), shows that there exists a significant difference between *all* of the treatments except for calcium hypochlorite and sodium hypochlorite for stone I. The summarized data is presented in Table 3.

	CaCl ₂ O ₂	Ba(OH) ₂	NaOCl	H ₂ O ₂	Control
Stone E - marble					
Average	8.16	4.43	3.65	5.75	1.88
Std Dev	4.27	2.81	1.48	2.02	0.83
Variance	18.23	7.92	2.18	4.07	0.69
Calculated F	26.50	11.51	3.17	5.92	N/A
Stone F - marble					
Average	4.66	16.87	6.82	7.69	7.73
Std Dev	2.76	12.67	2.47	3.03	5.26
Variance	7.64	160.65	6.09	9.20	27.63
Calculated F	3.62	5.81	4.54	3.00	N/A
Stone I - marble					
Average	3.30	3.86	2.89	1.20	3.99
Std Dev	1.84	3.14	1.02	0.52	1.31
Variance	3.37	9.86	1.05	0.27	1.72
Calculated F	1.95	5.71	1.65	6.40	N/A

Table 3. Summarized Micro-Drop Absorption Time Measurements for Marble, after first poulticing. F Values are calculated and compared to a tabulated F Value of 2.40 for 14 degrees of freedom, at a 95% Confidence Level. Time is given in seconds.

An Analysis of Variance test was then used to confirm the established differences. The test compares the averages between and within the four treatments groups. From statistical tables, using 4 and 70 degrees of freedom with a 95% confidence level, an F value of 2.53 was obtained for comparison of the Ratio of Mean Squares. As shown in Table 4, there are significant differences between the control and each of the treatments.

Stone E - marble	Sum of Squares	Degrees of Freedom	Mean Squares
Between Treatments	332.71	4	83.18
Within Treatments	463.22	70	6.62

Ratio of Mean Squares = **12.57**

Stone F - marble	Sum of Squares	Degrees of Freedom	Mean Squares
Between Treatments	1327.44	4	331.86
Within Treatments	2957.05	70	42.24

Ratio of Mean Squares = **7.86**

Stone I - marble	Sum of Squares	Degrees of Freedom	Mean Squares
Between Treatments	75.95	4	18.98
Within Treatments	227.72	70	3.25

Ratio of Mean Squares = **5.84**

Table 4. Analysis of Variance for Micro-Drop Absorption Time Measurements - First Poulticing. The Ratio of Mean Squares is compared with the tabulated F value of 2.53 for 4 and 70 degrees of freedom, at a 95% Confidence Level. Values greater than 2.53 indicate a significant difference.

5.5 Poultice Reapplication

After roughness and water absorption time was measured, the poultices were reapplied in the same manner albeit without the Japanese tissue paper. This was done to determine how many applications were needed to fully remove biological growth for each agent and to measure again any changes to the stone's surface.

Poultices were reapplied to the marbles in stages, i.e., all stones received the hydrogen peroxide treatment on one day, the barium hydroxide treatment on the next day, and so on. This was done to eliminate the previous problem of solutions spreading into other treatment areas.

A second application was not carried out on the sandstone due to the marked bleaching effect of the initial application. Because of this extreme color alteration it was determined that these cleaning agents would be inappropriate for this stone.

As nearly as can be determined macroscopically, the first application was sufficient to eliminate all the visible biological growth resident on the granite. A second poultice was not considered necessary.

5.6 Experimental Results after Second Poulticing

5.6.1 Visual Examination

All three stones exhibited an almost total elimination of residual biological growth. The hydrogen peroxide treatment area was noticeably whiter while the barium hydroxide treatment area became a darker brown.

5.6.2 Surface Roughness

Since surface roughness did not show a change during the first application, as confirmed by the statistical F Test, it was concluded that this procedure does not affect surface roughness and this parameter was not re-measured.

5.6.3 Micro-Drop Absorption Time

The micro-drop test was repeated a second time, resulting in 225 additional measurements. All data is given in Appendix E. Summarized data and the F values calculated are given in Table 5.

	CaCl ₂ O ₂	Ba(OH) ₂	NaOCl	H ₂ O ₂	Control
Stone E - marble					
Average	13.14	6.27	5.30	16.58	2.84
Std Dev	4.45	2.36	1.57	8.67	1.52
Variance	19.78	5.57	2.45	75.23	2.30
Calculated F	8.61	2.43	1.07	32.74	
Stone F - marble					
Average	7.25	16.80	7.07	19.50	6.52
Std Dev	4.44	5.38	4.51	8.51	3.39
Variance	19.67	28.98	20.32	72.43	11.46
Calculated F	1.72	2.53	1.77	6.32	
Stone I - marble					
Average	2.25	5.82	1.16	0.82	1.73
Std Dev	0.73	2.58	0.40	0.28	0.72
Variance	0.53	6.65	0.16	0.08	0.51
Calculated F	1.02	12.96	3.18	6.72	

Table 5. Summarized Micro-Drop Absorption Time Measurements of Marble, after second poulticing. F Values are calculated and compared to a tabulated F Value of 2.40 for 14 degrees of freedom, at a 95% Confidence Level. Time is given in seconds.

The F Test revealed that there again was a significant difference in the values for half of all readings as indicated in Table 4. An Analysis of Variance test was then applied using 4 and 70 degrees of freedom with a 95% confidence level. An F value of 2.53 was obtained from statistical tables for comparison against the Ratio of Mean Squares to determine if there was a significant difference between treatments. As indicated below, there is again a significant difference between the treatments and the control.

Stone E - marble	Sum of Squares	Degrees of Freedom	Mean Squares
Between Treatments	2001.29	4	500.32
Within Treatments	1474.77	70	21.07

Ratio of Mean Squares = **23.75**

Stone F - marble	Sum of Squares	Degrees of Freedom	Mean Squares
Between Treatments	2319.91	4	579.73
Within Treatments	2139.98	70	30.57

Ratio of Mean Squares = **18.96**

Stone I - marble	Sum of Squares	Degrees of Freedom	Mean Squares
Between Treatments	242.78	4	60.69
Within Treatments	111.04	70	1.59

Ratio of Mean Squares = **38.26**

Table 6. Analysis of Variance for Micro-Drop Absorption Time Measurements - Second Poulticing. The Ratio of Mean Squares is compared with the tabulated F value of 2.53 for 4 and 70 degrees of freedom, at a 95% Confidence Level. Values greater than 2.53 indicate a significant difference.

5.7 Discussion

The elimination of the biological growth and cleaning of the surface, in particular for the marbles, could be considered adequate after the application of two poultices. However, not all the materials tested performed the same way. Hydrogen peroxide bleached the surface far more than the hypochlorites. The barium hydroxide only killed the biological growth (which turned brown) but it could not be effectively removed by gentle brushing.

The application of the various poultices did not affect the surface roughness of the different stones. However, the water absorption characteristics were affected, as was demonstrated for the case of the marbles.

The summarized data of the water micro-drop absorption time is presented in Figure 8, following. For the case of the E and I stones, there is a significant difference between the first and the second poulticing.

Stone E shows significant differences between the absorption time of the control area and the treated areas, as apparent already in Tables 3 and 5. The increase in absorption time for the second poulticing for calcium hypochlorite and hydrogen peroxide can be explained as a function of the unevenness of the eroded stone surface which shows cracks and crevices, thus randomizing absorption time of the marble.

Stone F is made up of pure calcite grains of similar size and, hence, more compact. For this stone, no significant differences in water absorption are measured between the first and the second poulticing, and the control, except for the hydrogen peroxide which

appears to increase the water absorption time significantly. Note that for the barium hydroxide treatment, the standard deviation is unusually large for the first poultice, indicating a wide dispersion of data. The consolidating action of the barium hydroxide is reflected in a lack of increase of measured absorption times after the second poulticing.

Stone I, which has a sugaring surface and whose microstructure is the least homogenous, reflects this in the variation of measured absorption times. However, the average absorption times decrease as would be expected for a cleaning action. Note that standard deviations decrease on the second poulticing indicating less dispersion of data.

Differences in the absorption times can, in some cases, be attributed to variations in biological growth between the stones.

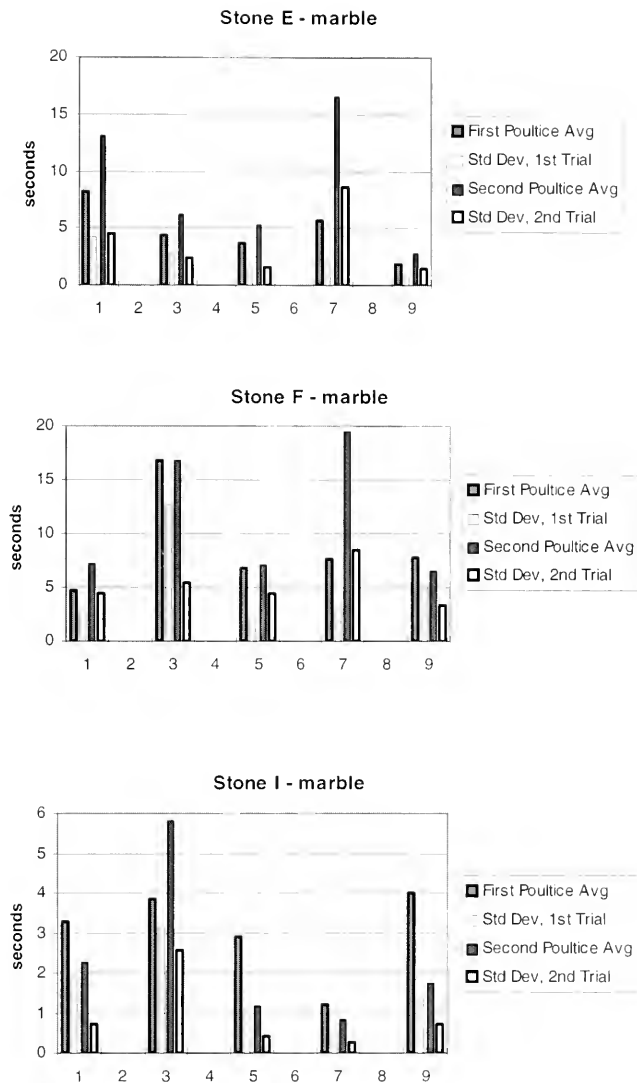


Figure 8. Micro-Drop Absorption Time Comparisons of Marbles.
 (1= CaCl_2O_2 , 3= $\text{Ba}(\text{OH})_2$, 5= NaOCl , 7= H_2O_2 , 9=Control)

Chapter 6: Laboratory Evaluation of Hygroscopicity After Chemical Treatment

6.1 Introduction

Hygroscopicity is a characteristic defined as the ability of a material to absorb water vapor from the air. Water vapor is the most available form of moisture (of the forms: liquid, vapor, solid) and interacts with the surface and subsurface of the material working to create an equilibrium between surface saturation and relative humidity of the surrounding air.

The stone's porosity and nature determine the amount and the rate of exchange of water with the environment. The surface atoms of an initially dry surface of a porous material such as marble will attract and continually absorb moisture (which then diffuses through the stone via its capillary system) until equilibrium in moisture content is achieved. This absorbed moisture is called hygroscopic moisture and the amount absorbed at the equilibrium point is called the equilibrium moisture content. A number of factors can affect this ability to attract moisture: temperature, pore size (smaller pores favor hygroscopic absorption), the presence of soluble salts, and surface coatings.

6.2 Experimental Program

Some of the agents tested in this program produce soluble salts, i.e., NaCl or CaCl₂, which could be left in the stone's pore system if not adequately removed. Therefore, a test was designed to ascertain the degree to which these salts could affect a stone's hygroscopic properties. The test consisted of exposing the stones to approximately 100% relative humidity (RH) to determine the amount of moisture absorbed.

6.2.1 Sample Preparation

Two types of stones were tested: a white marble from a broken gravestone obtained from Woodlands Cemetery in Philadelphia (provenance of the stone is unknown) and a red sandstone from Seneca Creek Quarry in Maryland.

Both samples were cut into five samples each, measuring 5cm x 5cm x 2cm, and were designated as A through E. All were mechanically polished as evenly as possible on all sides, using a 240 grit aluminum oxide powder.

The stones were then placed in a drying oven at 105°C for 24 hours. Samples were left to cool on a rack above a layer of anhydrous calcium sulfate (Drierite) in a dessicator chamber (Figure 10). Before each use, the Drierite was left in the oven for 24 hours, at a temperature of 105°C, to ensure elimination of all residual moisture. These steps were repeated until a constant weight was reached (Appendix F - Sample Weights).

6.2.2 Sample Treatment

The following chemical solutions were prepared (700mL each) in glass beakers:

33% w/v $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$ (barium hydroxide octahydrate) and glycerin

7% v/v NaOCl (sodium hypochlorite, 13% active chlorine)

3% w/v CaCl_2O_2 (calcium hypochlorite)

30% v/v H_2O_2 (hydrogen peroxide)

A single layer of 6mm glass beads was placed at the bottom of each beaker of solution. Two stones (one marble, one sandstone) were then placed in each beaker, upright on the beads, with the solution completely covering the stones. Two control stones were placed in beakers of deionized water.



Figure 9. Samples Totally Immersed in Treatment Solutions.

The beakers were covered tightly with plastic wrap and left for 3 1/2 hours. At the end of this period the stones were removed, gently rinsed with deionized water, and patted dry with paper towels. They were then placed back in the dessicator chamber to air dry. After 24 hours they were removed and weighed; this was repeated until a constant weight was reached (Appendix F - Sample Weights).

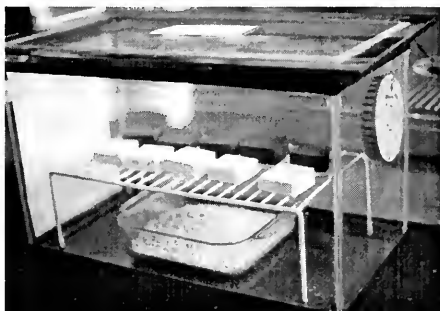


Figure 10. Dessicator Chamber.

The percent moisture and treatment residue in the samples, after treatment, were calculated and the results are presented in Table 7.

	% Moisture	% Treatment Residue
Sample A - Ba(OH)₂		
Marble	0.01	0.12
Sandstone	1.37	0.87
Sample B - NaOCl		
Marble	0.01	0.04
Sandstone	1.97	0.03
Sample C - CaCl₂O₂		
Marble	0.01	0.03
Sandstone	1.23	0.05
Sample D - H₂O₂		
Marble	0.01	0.01
Sandstone	1.31	-0.03

Table 7. Percent Moisture and Treatment Residue after Treatment.

6.3 Hygroscopicity Measurements

A layer of PVC rings were placed upright in a tub of 1" deep deionized water, with the top of the rings reaching approximately 1" above the surface of the water. The stones were laid on their large face on top of these rings. The tub was then sealed with several layers of plastic wrap and taped shut. For a one month period, the tub was opened weekly to weigh the stones then sealed shut again. Data are given in Table 8 and in Appendix F - Hygroscopicity.

	Start Weight	Week 1	Week 2	Week 3	Week 4
Sample A - Ba(OH)₂					
Marble	145.61	145.97	145.95	145.82	145.81
Sandstone	171.08	173.60	174.63	174.96	174.30
Sample B - NaOCl					
Marble	132.20	132.33	132.33	132.29	132.28
Sandstone	141.82	143.09	143.34	143.10	142.88
Sample C - CaCl₂O₂					
Marble	147.28	147.42	147.43	147.36	147.37
Sandstone	153.51	154.85	155.07	154.81	154.50
Sample D - H₂O₂					
Marble	127.13	127.20	127.21	127.17	127.18
Sandstone	176.02	176.98	177.05	176.87	176.71
Sample E - Control					
Marble	145.46	145.54	145.52	145.48	145.51
Sandstone	130.71	131.28	131.32	131.19	131.12

Table 8. Weight Increase (grams) due to Water Vapor Absorption.

6.3.1 Results

The data were graphed to facilitate interpretation (Figure 11). The graphs show the percentage of weight increase over four weeks time. The rapid initial weight increase evident for all samples can be explained by the drastic change in environment, from the dry dessicator chamber to the 100% RH of the plastic tub. As equilibrium conditions are established the curves level off.

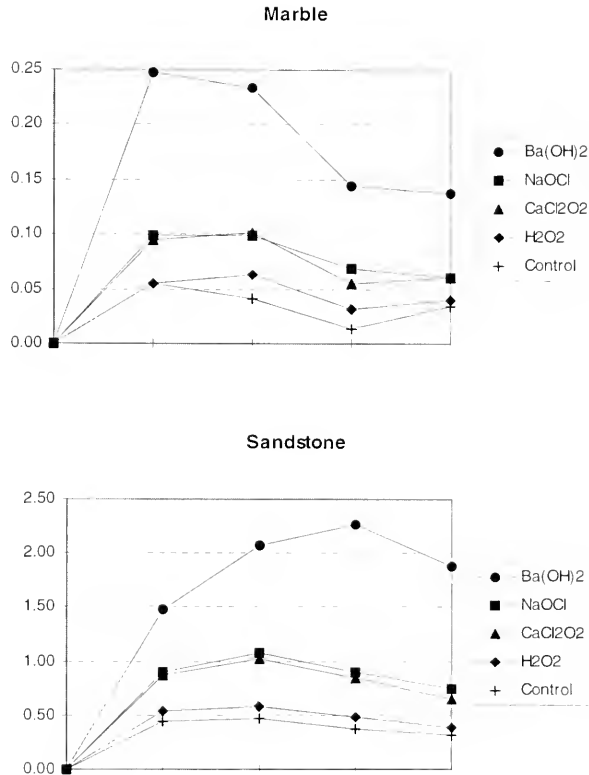


Figure 11. Hygroscopicity Test - Relative Weight Increase Percentage.

As expected, the hydrogen peroxide results match up closely with that of the control, indicating a very minimal increase in hygroscopicity. This is not the case for the sodium hypochlorite and calcium hypochlorite solutions, which read nearly identically. These reveal a doubling in percentage weight gain as compared to the control, indicating a marked augmentation in hygroscopicity due to the presence of salts, NaCl and CaCl₂,

both of which are hygroscopic at that RH. Calcium hypochlorite is known to be hygroscopic at any level of relative humidity, and sodium hypochlorite is notably hygroscopic at levels of 75% RH or greater. The higher increase for the barium hydroxide data is due to the acquisition of carbon dioxide from the atmosphere as carbonation proceeds.

6.4 Removal of Retained Salts

As described in previous chapters, the presence of salts can be destructive to stone substrates particularly when they crystallize, which occurs when ambient relative humidity is lower than the equilibrium relative humidity. This is the hygroscopic humidity of soluble salts (Andreas 1981) and the more soluble the salt the more hygroscopic they tend to be (Arnold 1984).

To investigate the removal of salts left behind after treatment the samples were washed with deionized water, knowing that the "...strong polarity of water molecules is one of the reasons why water is also able to dissolve ionic compounds (salts)..." (Moncrieff and Weaver 1984). Samples were put back into the dessicator chamber to air dry until constant weight was achieved. Each sample was then placed upright on a layer of 6mm glass beads, completely submerged in separate beakers of 700mL of deionized water, where they remained for three hours. The beaker solution was retained, while the samples were removed and blotted dry then returned to the dessicator chamber to again achieve constant weight.

6.4.1 Conductivity Measurements

To determine the effectiveness of salt removal by immersion, the conductivity of the residual water was measured (Alessandrini et al. 1993). Using an Extech Oyster pH/Conductivity Plus Meter, the electrical conductivity of each beaker solution was measured, as well as that of deionized water. The conductivity cell was rinsed each time with deionized water to prevent contamination, and calibration was performed between each reading using a 0.01M potassium chloride solution. Room temperature was 25°C and the meter was calibrated to 1.41mS/cm. Data readings are included in Appendix F - Specific Conductivity Measurements. Specific conductance for each sample was averaged from six readings and is given below in Table 9.

	Sample A- Ba(OH) ₂	Sample B- NaOCl	Sample C- CaCl ₂ O ₂	Sample D- H ₂ O ₂	Sample E- Control	H ₂ O
Marble	0.43	0.43	0.45	0.44	0.42	0.01
Sandstone	0.45	0.47	0.48	0.47	0.47	0.01

Table 9. Conductivity Measurements (mS/cm).

The conductance of the residue left by the treatment was calculated, and presented in Table 10, adapting the NORMAL 13/83 (1983) procedure as follows.

Conductance =

$$\frac{\text{Specific Conductivity of Solution} - \text{Specific Conductivity of Deionized Water}}{\text{Treatment Residue}} \times 100$$

	Sample A	Sample B	Sample C	Sample D
Marble	2.47	8.40	11.0	43.0
Sandstone	0.31	11.5	5.87	--

Table 10. Percent Specific Conductance.

The higher conductance readings reflect the lower amount of residue left behind since the specific conductivity measured was similar for all solutions. This similarity in readings is due to a problem experienced with the deionizing filters. It was discovered, after the samples were soaked in deionized water, that the filters were not working properly and therefore conductance readings were not accurately reflecting the amount of residual salts.

6.5 Residual Hygroscopicity

After the samples were dried to constant weight, they were returned to the 100% RH environment as described in section 6.3. As before, samples were weighed at the end of each week for four weeks.

	Start Weight	Week 1	Week 2	Week 3	Week 4
Sample A - Ba(OH)₂					
Marble	145.54	145.57	145.55	145.55	145.55
Sandstone	170.67	172.35	172.57	172.68	172.51
Sample B - NaOCl					
Marble	132.20	132.23	132.21	132.21	132.22
Sandstone	141.82	142.71	142.62	142.68	142.69
Sample C - CaCl₂O₂					
Marble	147.29	147.32	147.30	147.30	147.31
Sandstone	153.52	154.43	154.32	154.41	154.50
Sample D - H₂O₂					
Marble	127.13	127.15	127.13	127.13	127.14
Sandstone	176.04	176.84	176.71	176.79	176.78
Sample E - Control					
Marble	145.47	145.51	145.48	145.48	145.48
Sandstone	130.76	131.26	131.20	131.23	131.21

Table 11. Hygroscopicity Weights after Soaking in Water.

An initial peak is again evident, with a lessening and levelling off as equilibrium is reached. For the sandstone samples, the hydrogen peroxide sample again closely followed the control and the two hypochlorites matched each other. The hypochlorites also, again, showed a nearly doubled weight increase as compared to the hydrogen peroxide treated sample and the control sample. The marble samples also followed a pattern similar to that shown after the first trial but at a much lower level. The data are graphed (Figure 12, following) using previous scales (Figure 11) for easier comparison.

6.6. Discussion

As mentioned previously, hygroscopicity is both a function of the nature and the porosity of the stone. Among the various rock-forming minerals, clays are those that have a high degree of hygroscopicity. The sandstone used in this test contains a high clay content. This is reflected in the control sample's relative weight increase of around 0.5%, as compared to the marble control for which this value is ten times lower.

As was to be expected, treatment with hydrogen peroxide did not affect hygroscopicity and the curves followed that of the control sample.

Both hypochlorite solutions leave behind soluble salts of hygroscopic nature, increasing hygroscopicity significantly and doubling the relative amount of moisture absorbed.

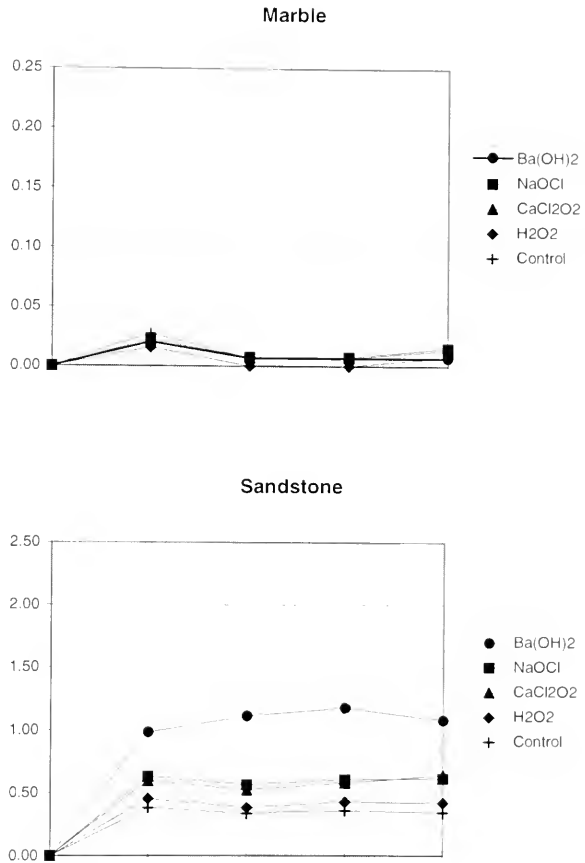


Figure 12. Hygroscopicity Test - Relative Weight Increase Percentage After Soaking.

The case of barium hydroxide is more complex, since in this case not only moisture but carbon dioxide are taken from the air, which is reflected in the reported curves (see Figures 11 and 12). Some of the unreacted base may have been removed (initial weight after soaking is lower than original) and is reflected in the lower absorption followed in the second run. However, the soaking may have brought out the residual Ba^{++} ions to the surface thus forming the visible efflorescence which increased with time.

The three hour soaking was apparently sufficient to remove nearly all of the soluble salts present so that they no longer result in an increase of hygroscopicity. This is evident for both the marble and the sandstone samples, which in the second run absorbed moisture at the same levels as the control samples.

Chapter 7: Discussion of Conclusions

7.1 Summary

In chapter one, the origin and historical background of the statuary was discussed. Although early nineteenth century photographs document the presence of many of the current statues, no date has been confirmed as to their initial acquisition. It is thought that the pieces were placed on the grounds in the late eighteenth century. Historical paintings and drawings carried out shortly after the Battle of Germantown, in 1777, show statues of similar likeness to those currently in place. Eighteenth century correspondence between Benjamin Chew, the owner of Cliveden, and various family members discusses the disposition of outdoor statuary of similar description. The only solid evidence found so far confirms the presence in 1771 of the two lions at the front entrance.

The next chapter discusses each piece and its physical condition, with some explanation as to how microclimate can influence conditions. Because the focus of this investigation is the biodeterioration of these statues, chapter three then outlines the various forms of biological growth and their affect on stone, with chapter four discussing the historical methods for treatment along with federal legislation regarding current products. As it becomes more difficult to meet expanding environmental and health regulations in designing and manufacturing new biocidal products, a second look at simpler methods of treatment is warranted. It must be kept in mind, however, that any product must still meet restrictions placed on use and disposal.

7.2 Laboratory Investigations

The outdoor marble statuary at Cliveden, in Germantown, Pennsylvania, and their cleaning and conservation was the subject matter around which laboratory investigations were designed. These investigations were to explore the use of cleaning agents as biocides and to test and evaluate them in the laboratory prior to field tests. They were carried out on similar marbles to ascertain their probable effectiveness on the statuary. Although the focus is on marble, some tests were also conducted on sandstone and granite samples for a comparison of stone type properties.

While the primary purpose of using a biocidal agent is to kill and remove the biological growth, the process inherently carries with it other effects. Although this is known, it has not been sufficiently investigated and documented. The adverse effects can sometimes cancel out the alluring aspects of a treatment and knowing what those are ahead of time can aid the conservator in making a wise choice. These effects include alterations to the stone as well as exposure to possible health hazards during their application. Given the complex legislation for the application and use of biocides, this thesis has focused only on cleaning agents, including an inorganic consolidant.

The chemicals chosen for the investigation included: sodium hypochlorite (NaOCl), calcium hypochlorite (CaCl_2O_2), hydrogen peroxide (H_2O_2), and barium hydroxide ($\text{Ba}(\text{OH})_2$). The first three are oxidizing agents and are commercially available. They have traditionally been used in the bleaching of paper and textiles and in the cleaning of stone (Leznicka, et al 1988; Nugari, et al 1993; Tudor, et al 1990). Barium hydroxide,

which requires some customization, has been used as a consolidant for calcareous stones and its biocidal action on algal growth noted as a side effect.

The first part of this investigation was an evaluation of cleaning through a chemical poulticing. This included a visual examination and measurements of surface roughness and water micro-drop absorption time after treatment. Roughness was measured with a profilometer with nearly a hundred measurements taken for each stone, thus providing sufficient data to perform a statistical analysis on the results. The micro-drop absorption time was measured using an adaptation of a RILEM test, releasing a single drop of water onto the stone's surface and timing its total absorption. This test required a similar number of measurements, but was conducted on the marbles only since they are the focus of this study. The poulticing was applied a second time, to ascertain the extent to which a second application would further remove biological growth. The micro-drop absorption time was then reexamined.

Based upon the statistical F Test, it can be concluded that surface roughness was not affected in any of the treatment areas, for any of the stones.

The results of the micro-drop absorption tests indicate that there were some changes to the water absorption properties of the marbles. Statistical analysis (the F Test) shows that, in general, a significant difference exists for all three marbles when comparing the control to the treated area after the first poulticing, so it can then be concluded that this property *is* altered by chemical treatment. After a second poulticing, the F Test reveals

that for nearly half of the treatments no significant difference is apparent with respect to the control area.

Visually, the most successful of the four treatments was the hydrogen peroxide. It gave a whitened appearance to the marble, and both killed and facilitated the removal of the biological growth. The barium hydroxide succeeded in killing the biogrowth, but did not aid in removing it, and left a brown discoloration. The hypochlorites were successful in both destroying and removing the growth, but less so than the hydrogen peroxide.

The second part of this study dealt with the effect the treatments had on the hygroscopic properties of stone. For this purpose, a marble and sandstone were used. The samples were treated with the same solutions used for the poulticing. They were then exposed to a 100% relative humidity (RH) environment and weighed repetitively for four weeks to determine if the treatment resulted in a weight increase due to water vapor absorption.

The hypochlorite-treated samples displayed a notable weight increase, due to the presence of the residual hygroscopic salts NaCl and CaCl_2 . The sample treated with barium hydroxide showed an increase due to the acquisition of CO_2 from the atmosphere. The sample treated with hydrogen peroxide behaved much like the control, showing no increase in hygroscopicity as evidenced by a minimal weight gain since it does not leave behind soluble salts.

Weight increases were confirmed as being caused by the presence of hygroscopic salts by soaking the samples in deionized water in an attempt to remove residual salts.

Subsequent exposure to the same 100%RH environment for the same time period showed marked decrease in moisture absorption.

Cleaning treatments based on hypochlorites do not alter surface roughness nor significantly change the micro-drop water absorption times. They do, however, increase hygroscopicity if residual salts are not removed.

Barium hydroxide, although bestowing consolidating effects, does not appear to achieve the goal of both control and cleaning of biological growth. Although it does not increase surface roughness, it does appear to alter micro-drop water absorption time.

Based on the laboratory tests performed, a field test can be designed as follows:

1. Application of an H_2O_2 poultice for cleaning and removal of biological growth.
2. Application of a $\text{Ba}(\text{OH})_2$ poultice to increase surface cohesiveness and reduce water absorption.

These field tests require the development of a field evaluation program before the actual sculptures can be treated. The field test could be applied to some of the less visible pieces of statuary (such as the small pedestal) and the evaluation program would rely on visual examination with a hand lens and water absorption tests with a water pipe.

The proposed program would serve to eliminate the visible growth, would consolidate the eroded surface, and the presence of Ba^{++} would hopefully prevent recolonization.

Bibliography

Algae, Fungi and Lichens. filmstrip. 1972. Eye Gate House.

Alessandrini, G., L. Toniolo, A. Antonioli, A. Di Silvestro, F. Piacenti, S. Righini Ponticelli, and L. Formica. 1993. "On the Cleaning of Deteriorated Stone Minerals." In *Conservation of Stone and Other Materials*. Proceedings of the International RILEM/UNESCO Congress, Paris, 29 June -1 July, 1993, ed. M.-J. Thiel. London: E&FN Spon, 503-11.

Allsopp, C. and D. Allsopp. 1983. "An Updated Survey of Commercial Products Used to Protect Materials Against Biodeterioration." *International Biodeterioration Bulletin* 19(3/4):99-146.

Andreas, A. 1981. "Nature and Reactions of Saline Minerals in Walls." In *The Conservation of Stone II*. Preprints of the Contributions to the International Symposium, Bologna, 1981, ed. R. Rossi-Manaresi. Bologna: Centro per la Conservazione Delle Sculture all' Aperto, 13-23.

Andrew, C. M.E. Young, and K. Tonge. 1994. *Stonecleaning. A Guide for Practitioners*. Edinburgh: Historic Scotland and The Robert Gordon University.

Arnold, A. 1984. "Determination of Mineral Salts from Monuments." *Studies in Conservation* 29:129-138.

Ashurst, J. and F.G. Dimes. 1977. *Stone Building, its use and potential today*. London: The Architectural Press Ltd.

Ashurst, N. 1994. *Cleaning Historic Buildings*. London: Donhead Publishing Ltd.

Aspelin, A.L., J.A. Alsadek, and D.R. Stubbs. August 1992. "Chemicals Registered for the First Time as Pesticidal Active Ingredients Under FIFRA." Report held by Office of Pesticide Programs, U.S. Environmental Protection Agency.

Awasthi, Dharani Dhar. 1991. "Lichens and Monuments." In *Biodeterioration of Cultural Property*. Proceedings of the International Conference held in Lucknow, India, 20-25 February 1989, ed. O.P. Agrawal, Shashi Dhawan. New Delhi: Macmillan India Limited, 207-211.

Ashton, F.M. and A.S. Crafts. 1981. *Mode of Action of Herbicides*. 2nd Edition. New York: John Wiley & Sons.

Barov, Zdravko. 1987. "An Effective Cleaner for Organic Stains on Stone." In *Preprints*, ICOM Committee for Conservation, 8th Triennial Meeting, Australia, 6-11 September 1987. ed. K. Grimstad. Los Angeles: Getty Conservation Institute, 465-468.

- Bech-Anderson, J. 1984. "Biodeterioration of Natural and Artificial Stone Caused by Algae, Lichens, Mosses and Higher Plants. In *Biodeterioration 6*. 6th International Symposium, Washington D.C., August 1984. New York: John Wiley & Sons.
- Bock, E., W. Sand, M. Meincke, B. Wolters, B. Ahlers, C. Meyer and F. Sameluck. 1987. "Biologically Induced Corrosion of Natural Stones - Strong Contamination of Monuments with Nitrifying Organisms." In *Biodeterioration 7*, papers presented at the 7th International Biodeterioration Symposium, U.K., 6-11 September 1987, ed. D.R. Houghton, R.N. Smith, and H.O.W. Egging. London: Elsevier Applied Science, 436-440.
- Building Research Establishment. 1992. *Control of Lichens, Moulds and Similar Growths*. Digest 370E.
- Camuffo, D. 1991. "Environment and Microclimate." In *Science, Technology and European Cultural Heritage*. Proceedings of the European Symposium, Bologna, Italy, 13-16 June 1989. ed. N.S. Baer, C. Sabbioni, and A.I. Sors. Luxembourg: Butterworth-Heinemann Ltd., 37-50.
- Camuffo, D. and A. Bernardi. 1991. "Indoor and Outdoor Microclimate Case Studies: The Trajan Column and Sistine Chapel." In *Science, Technology and European Cultural Heritage*. Proceedings of the European Symposium, Bologna, Italy, 13-16 June 1989. ed. N.S. Baer, C. Sabbioni, and A.I. Sors. Luxembourg: Butterworth-Heinemann Ltd., 295-301.
- Caneva, G., M.P. Nugari, and O. Salvadori. 1991. *Biology in the Conservation of Works of Art*. Rome.
- Charola, A.E., C.A. Grissom, E. Erder, M.J. Wachowiak, and D. Oursler. 1996. "Measuring Surface Roughness: Three Techniques." In *Proceedings of the 8th International Congress on Deterioration and Conservation of Stone*, Berlin, 30 Sept - 4 Oct 1996. ed. J.Riederer. Berlin: Moeller Druck und Verlag, 1421-1434.
- Clifton, James R. 1980. *Stone Consolidating Materials - A Status Report*. National Bureau of Standards Technical Note 1118. U.S. Government Printing Office.
- Cook, L.A. 1989. "The Effects of Herbicides on Masonry: Products, Choices and Testing." Thesis. Columbia University.
- Durovic M., and J. Zelinger. 1988. "Chemical Processes in the Bleaching of Paper in Library and Archival Collections." *Restaurator* 14 (2):78-101.
- Eberlein, H.D. and H.M. Lippincott. 1912. *The Colonial Homes of Philadelphia and its Neighborhood*. Philadelphia: J.B. Lippincott Company.
- Environmental Protection Agency. December 1988. Highlights of the 1988 Pesticide Law.

- Environmental Protection Agency. May 1991. EPA's Pesticide Programs, #21T-1005.
- Environmental Protection Agency. April 1994. Pesticide Reregistration Program Report, #EPA 738-R-94-009.
- Environmental Protection Agency. January 1995. Office of Pesticide Programs Annual Report for 1994, #EPA 735-R-95-001.
- European Federation of Corrosion Publications, No. 9. 1992. "Microbiological Degradation of Materials - and Methods of Protection, A Working Party Report". The Institute of Materials, 4-23.
- Feddema, J.J. 1986. "Air Pollution Effects on Marble Weathering in Philadelphia, Pennsylvania." *Publications in Climatology* 39(1): University of Delaware.
- Feddema, J.J. and T.C. Meierding. 1991. "Marble Deterioration in the Urban Atmosphere." In *Science, Technology and European Cultural Heritage*. Proceedings of the European Symposium, Bologna, Italy, 13-16 June 1989. ed. N.S. Baer, C. Sabbioni, and A.I. Sors. Luxembourg: Butterworth-Heinemann Ltd., 443-446.
- Frey, T., von Reis, J., Barov, Z. 1993. "An Evaluation of Biocides for Control of Biodeterioration of Artifacts at Hearst Castle." In *Preprints*, 10th Triennial Meeting, Washington D.C., ed. J. Bridgland, Paris: ICOM, 875-881.
- Gauri, K.L., A.N. Chowdhury, N.P. Kulshreshtha and A.R. Punuru. 1989. "The Sulfation of Marble and the Treatment of Gypsum Crusts." *Studies in Conservation* 34:201-206.
- Gauri, K.L., L. Parks, J. Jaynes, and R. Atlas. 1992. "Removal of sulphated-crust from marble using sulphate-reducing bacteria." In *Stone Cleaning and the Nature, Soiling and Decay Mechanisms of Stone*. Proceedings of The International Conference held in Edinburgh, UK, 14-16 April 1991, ed. R.G.M. Webster. London, U.K.: Donhead Publishing, 160-165.
- Grant, C. and A.F. Bravery. 1981. "Laboratory Evaluation of Algicidal Biocides for Use on Constructional Materials. 1. An Assessment of Some Current Test Methods." *International Biodeterioration Bulletin* 17(4):113-123.
- Hale Jr., M.E. 1975. "Control of Biological Growths on Mayan Archeological Ruins in Guatemala and Honduras." *National Geographic Society Research Reports*. 305-321.
- Hansen, J. 1980. "Ailing Treasures." *Science* 80 1(6):58-61.
- Hueck-van der Plas, E.H. 1968. "The Micro-Biological Deterioration of Porous Building Materials." *International Biodeterioration Bulletin* 4(1):11-28.

- Jain, K.K., V.K. Saxena, and T. Singh. 1991. "Studies on the Effect of Biogenic Acids on Stone Materials." In *Biodeterioration of Cultural Property*. Proceedings of the International Conference held in Lucknow, India, 20-25 February 1989, ed. O.P. Agrawal, Shashi Dhawan. New Delhi: Macmillan India Limited, 240-248.
- Jones, D., and M.J. Wilson. 1985. "Chemical Activity of Lichens on Mineral Surfaces - A Review." *International Biodeterioration* 21(2):99-104.
- Jones, D., M.J. Wilson, and W.J. McHardy. 1987. "Effects of Lichens on Mineral Surfaces." In *Biodeterioration 7*, papers presented at the 7th International Biodeterioration Symposium, U.K., 6-11 September 1987, ed. D.R. Houghton, R.N. Smith, and H.O.W. Egging. London: Elsevier Applied Science, 129-134.
- Keller, W.D. and A.F. Frederickson. 1952. "Role of Plants and Colloidal Acids in the Mechanism of Weathering." *American Journal of Science* 250:594-608.
- Kirk-Othmer. 1992. *Encyclopedia of Chemical Technology*, Fourth Edition (4): 271-294, 304.
- Knopman, D.S. 1975. "Conservation of Stone Artworks: Barely a Role for Science." *Science* 190:1187-1188.
- Koestler, R.J., A.E. Charola, M. Wypyski, and J.J. Lee. 1992. "Microbiologically Induced Deterioration of Dolomitic and Calcitic Stone as Viewed by Scanning Electron Microscopy." In Proceedings, *7th International Congress on Deterioration and Conservation of Stone*, eds. J.D. Rodrigues, F. Henriques and F.T. Jeremias, Portugal: Laboratorio Nacional de Engenharia Civil, 616-626.
- Krumbein, W.E. 1987. "Microbial Interactions with Mineral Materials." In *Biodeterioration 7*, papers presented at the 7th International Biodeterioration Symposium, U.K., 6-11 September 1987, ed. D.R. Houghton, R.N. Smith, and H.O.W. Egging. London: Elsevier Applied Science, 78-100.
- Krumbein, W.E. 1992. "Colour Changes of Building Stones and Their Direct and Indirect Biological Causes." In Proceedings, *7th International Congress on Deterioration and Conservation of Stone*, eds. J.D. Rodrigues, F. Henriques and F.T. Jeremias, Portugal: Laboratorio Nacional de Engenharia Civil, 444-452.
- Krumbein, W.E., and M.Gross. 1992. "Interactions of Biocides with Cultures of Biodeteriorating Microbiota in Agar Diffusion and Rock Cube Tests." In Proceedings, *7th International Congress on Deterioration and Conservation of Stone*, eds. J.D. Rodrigues, F. Henriques and F.T. Jeremias, Portugal: Laboratorio Nacional de Engenharia Civil, 501-509.
- Krumbein, W.E., S.E. Diakumaku, K. Petersen, T. Warscheid, and C. Urzi. 1993. "Interactions of Microbes with Consolidants and Biocides Used in the Conservation of Rocks and Mural Paintings." In *Conservation of Stone and Other Materials*.

- Proceedings of the International RILEM/UNESCO Congress, Paris, 29 June -1 July, 1993, ed. M.-J. Thiel. London: E&FN Spon, 589-596.
- Krumbein, W.E., and C.E. Urzi. 1993. "Biodeterioration Processes of Monuments as a Part of (Man-Made?) Global Climate Change." In *Conservation of Stone and Other Materials*. Proceedings of the International RILEM/UNESCO Congress, Paris, 29 June -1 July, 1993, ed. M.-J. Thiel. London: E&FN Spon, 558-564.
- Laurenzi Tabasso, M., and A.M. Mecchi. 1984. "Proposal for a Methodology to Evaluate the Possible Damage Produced in Stones by Chemical Cleanings." In Proceedings, *5th International Congress on Deterioration and Conservation of Stone*, Lausanne, ed. G. Felix. Lausanne: Presses Polytechniques Romandes, 975-982.
- Lewin, S.Z. Patent #3,577,244.
- Lewin, S.Z. 1971. "Preserving Decayed Stone Sculpture." *National Sculpture Review* 20(4):22-27.
- Lewin, S.Z. and N.S. Baer. 1974. "Rationale of the Barium Hydroxide-Urea Treatment of Decayed Stone." *Studies in Conservation* 19:24-35.
- Leznicka., S., A. Strzelczyk and D. Wandrychowska. 1988. "Removing of Fungal Stains from Stone-works." In Proceedings, *Vlth International Congress on Deterioration and Conservation of Stone*, Torun, 12-14 Sept 1988, ed. J. Ciabach. Torun: Nicholas Copernicus University Press Department, 102-110.
- Lienardy, A., and P. Van Damme. 1988. "A Bibliographical Survey of the Bleaching of Paper." *Restaurator* 9(4):178,198.
- Maravelaki, P., G. Biscontin, R. Polloni, W. Cecchetti, E. Zendri. 1992. "Investigation on Surface Alteration of Limestone Related to Cleaning Processes." In Proceedings, *7th International Congress on Deterioration and Conservation of Stone*, eds. J.D. Rodrigues, F. Henriques and F.T. Jeremias, Portugal: Laboratorio Nacional de Engenharia Civil, 1093,1101.
- Merck Index. 1989. Eleventh Edition. ed. S. Budavari. New Jersey: Plerck & Co., Inc.
- Messner, K. 1989/90/91. "Bleaching Procedures to Remove Foxing Stains from Paper Objects." *Wiener Berichte Über Naturwissenschaft in der Kunst* 6/7/8:346-361.
- Moncrieff, A., and G. Weaver. 1983. *Science for Conservators*, Book 2, Cleaning. London: Crafts Council.
- NORMAL 13/83 Recommendation. 1983. Dosaggio dei sali solubili (Determination of Total Amount of Soluble Salts). CNR (Consiglio Nazionale della Ricerca Centri di Studio sulle Cause di Deperimento e sui Metodi di Conservazione delle Opere d'Arte) - ICR (Istituto Centrale per il Restauro), Roma.

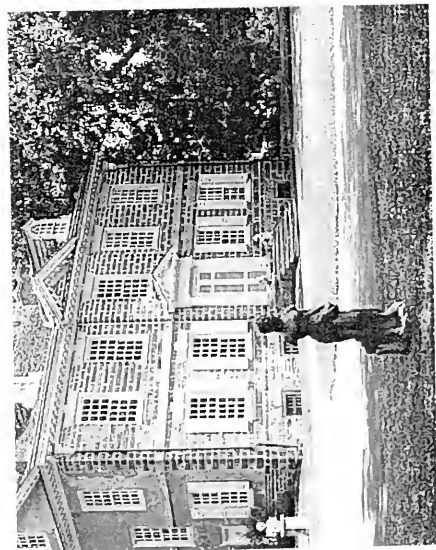
- Nugari, M.P., M.S. D'Urbano, and O. Salvadori. 1993. "Test Methods for Comparative Evaluation of Biocide Treatments." In *Conservation of Stone and Other Materials*. Proceedings of the International RILEM/UNESCO Congress, Paris, 29 June - 1 July, 1993, ed. M.-J. Thiel. London: E&FN Spon, 565-572.
- Nugari, M.P., P. Palleschi, and D. Pinna. 1993. "Methodological Evaluation of Biocidal Interference with Stone Materials - Preliminary Laboratory Tests." In *Conservation of Stone and Other Materials*. Proceedings of the International RILEM/UNESCO Congress, Paris, 29 June - 1 July, 1993, ed. M.-J. Thiel. London: E&FN Spon, 295-302.
- Quayle, N.J.T. 1995. "Report on Investigation into Right Biocides." *Conservation News* 57:25-28.
- Robert Gordon University. 1996. "Appendix C: Some Algicides/General Biocides Currently Approved for Use and Sale as Masonry Biocides by the Health and Safety Executive" *Biocides*. Fourth Draft:29-30, 82-87. Copy provided by Dennis Urquhart.
- Roby, T.C. 1996. "The Conservation of Funerary Monuments at the Protestant Cemetery (Cimitero Acattolico) in Rome: Initial Treatment of the Lady Temple Memorial." In *Preprints, Volume II, 11th Triennial Meeting*, Edinburgh, Scotland, 1-6 September 1996. London: ICOM, 810-815.
- Sadiri, H. 1988. The Deterioration and Conservation of Stone Historical Monuments in Indonesia." In Proceedings, VIth International Congress on Deterioration and Conservation of Stone, Torun, 12-14 Sept 1988. ed. J. Ciabach. Torun: Nicholas Copernicus University Press Department, 722-731.
- Saxena, V.K., K.K. Jain, and T. Singh. 1991. "Mechanisms of Biologically Induced Damage to Stone Materials." In *Biodeterioration of Cultural Property*. Proceedings of the International Conference held in Lucknow, India, 20-25 February 1989, ed. O.P. Agrawal, Shashi Dhawan. New Delhi: Macmillan India Limited, 249-258.
- Schnabel, L. 1988. "Laboratory Assessment of the Barium Hydroxide-Urea Process for the Consolidation of Limestone and Marble." Thesis. Columbia University.
- Schnabel, L. 1992. "Evaluation of the Barium Hydroxide-Urea Consolidation Method." In *Proceedings, 7th International Congress on Deterioration and Conservation of Stone*, eds. J.D. Rodrigues, F. Henriques and F.T. Jeremias, Portugal: Laboratorio Nacional de Engenharia Civil, 1063-1072.
- Seaward, M.R.D., and C. Giacobini. 1991. "Lichens as Biodeteriorators of Archeological Materials, with Particular Reference to Italy." In *Biodeterioration of Cultural Property*. Proceedings of the International Conference held in Lucknow, India, 20-25 February 1989, ed. O.P. Agrawal, Shashi Dhawan. New Delhi: Macmillan India Limited, 195-206.

- Sereda, P.J., and R.F. Feldman. October 1970. "Wetting and Drying of Porous Materials." *Canadian Building Digest* 130:130-4.
- Tendulkar, S.R. 1993. Bleaching Hosiery Fabric by Usage of Hydrogen Peroxide." *Textile Dyer & Printer* 26(1):24-26.
- Tudor, P.B. 1989. "The Restoration of a Marble Statue in New Orleans, Louisiana: A Case Study." Masters thesis. Columbia University.
- Tudor, P.B., F.G. Matero, and R.J. Koestler. 1990. "A Case Study of the Compatibility of Biocidal Cleaning and Consolidation in the Restoration of a Marble Statue." *Biodeterioration Research* 3:525-533.
- Twilley, J. 1984. "The Relationship of Microstructure to Treatment Variables in the Consolidation of Limestone with Barium Compounds." In *AIC Preprints*, Los Angeles, CA, 15-20 May 1984. Washington DC: American Institute for Conservation of Historic and Artistic Works, 79-85.
- Urmeneta, M.A., F.J. Sainz De Cueto, J.M.M. Pozas, and J.A.D. Torres. 1993. "Study of Patinas on Ornamental Stone." In *Conservation of Stone and Other Materials. Proceedings of the International RILEM/UNESCO Congress, Paris, 29 June - 1 July, 1993*, ed. M.-J. Thiel. London: E&FN Spon, 59-66.
- Urquhart, D.C.M., M.E. Young, R.D. Wakefield, K. Tonge, and K. Nicholson. 1996. "A Field Investigation of Algal Growths and Biocide Efficacy on Sandstone Buildings and Monuments." *Journal of Architectural Conservation* 2(1):55-73.
- Urzi, C.E., W.E. Krumbein, and A. Pernice. 1992. "Microbiological Investigations on the Biodeterioration and Decomposition of Marbles." In *Proceedings, 7th International Congress on Deterioration and Conservation of Stone*, eds. J.D. Rodrigues, F. Henriques and F.T. Jeremias, Portugal: Laboratorio Nacional de Engenharia Civil, 429-435.
- Urzi, C., G. Criseo, W.E. Krumbein, U. Wollenzien, and A.A. Gorbushina. 1993. "Are Colour Changes of Rocks Caused by Climate, Pollution, Biological Growth, or by Interactions of the Three?" In *Conservation of Stone and Other Materials. Proceedings of the International RILEM/UNESCO Congress, Paris, 29 June - 1 July, 1993*, ed. M.-J. Thiel. London: E&FN Spon, 279-286.
- Verges, V. 1996. "Towards a Definition of Common Evaluation Criteria for the Cleaning of Porous Building Materials: A Review." *Science and Technology for Cultural Heritage* 5(1):69-83.
- Verhoef, L.G.W., ed. 1988. *Soiling and Cleaning of Building Facades. A Report of Technical Committee 62SCF RILEM*. New York: Chapman and Hall, Ltd.

- Vos, B.H. 1975. "Waterabsorption and Drying of Materials." In *The Conservation of Stone I*. Proceedings of the International Symposium, Bologna, 1975. ed. R. Rossi-Manaresi. Bologna: Centro per la conservazione delle sculture all'aperto, 679-694.
- Watson, J.F. 1877 *Watson's Annals of Philadelphia*. Philadelphia: E.S. Stuary Co.
- Web site for U.S. Environmental Protection Agency: <http://www.epa.gov>
- Veeco Stylus Profiler Application web site: <http://www.veeco.demon.co.uk/texture.htm>
- Werner, M. 1991. "Changes of Surface Characteristics of Sandstone Caused by Cleaning Methods Applied to Historical Stone Monuments." In *Durability of Building Materials and Components*. Proceedings of the Fifth International Conference, Brighton, U.K., 1990. London: E.&F.N. Spon.
- Wilimzig, M., and E. Bock. 1995. "Biological Material Testing." In *Methods of Evaluating Products for the Conservation of Porous Building Materials in Monuments*, International Colloquium. Rome: ICCROM, 87-92.
- Winkler, E.M. 1966. "Important Agents of Weathering for Building and Monumental Stone." *Engineering Geology* 1(5):381-400.
- Young, G.S. and I.N.M. Wainwright. 1995. "The Control of Algal Biodeterioration of a Marble Petroglyph Site." *Studies in Conservation* 40(2):82-91.
- Young, M.E. 1993. "Stonecleaning of granite buildings and Monuments: the Use of Colour Measurement in Stonecleaning Trials." In *Conservation Science in the U.K.*, Preprints of the Meeting Held in Glasgow, May 1993, ed. Norman H. Tennent, London: James & James (Science Publ.), Ltd., 20-28.
- Young, M.E., R. Wakefield, D.C.M. Urquhart, K. Nicholson and K. Tonge. 1995. "Assessment in a Field Setting of the Efficacy of Various Biocides on Sandstone." In *Methods of Evaluating Products for the Conservation of Porous Building Materials in Monuments*, International Colloquium. Rome: ICCROM, 93-99.

Appendix A - Photos

- A-1. Cliveden, Map of Grounds.
- A-2. Lions.
- A-3. Female and Male Busts.
- A-4. Standing Figure and Torso.
- A-5. Standing Headless Male and Female.
- A-6. Small Pedestal and Large Pedestal.
- A-7. Urn and Pedestal with Base.
- A-8. Base with Feet and Ball.
- A-9. Details of Biological Growth.
- A-10. Details of Biological Growth.
- A-11. Details of Biological Growth.



84



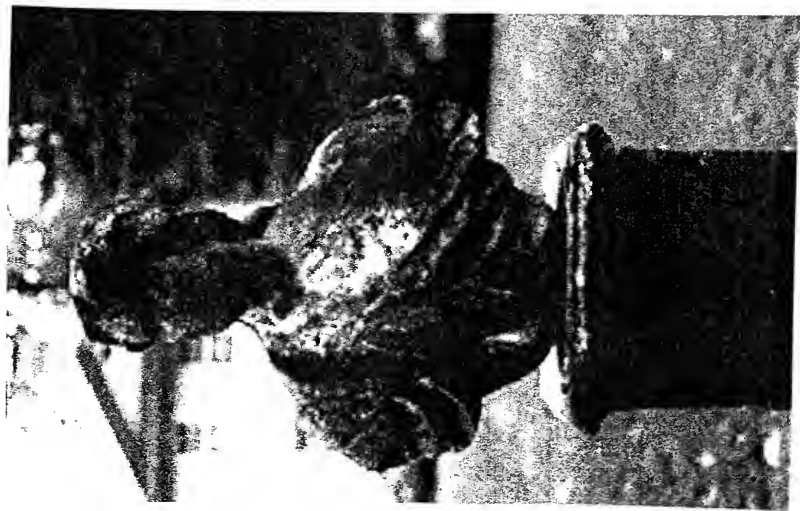
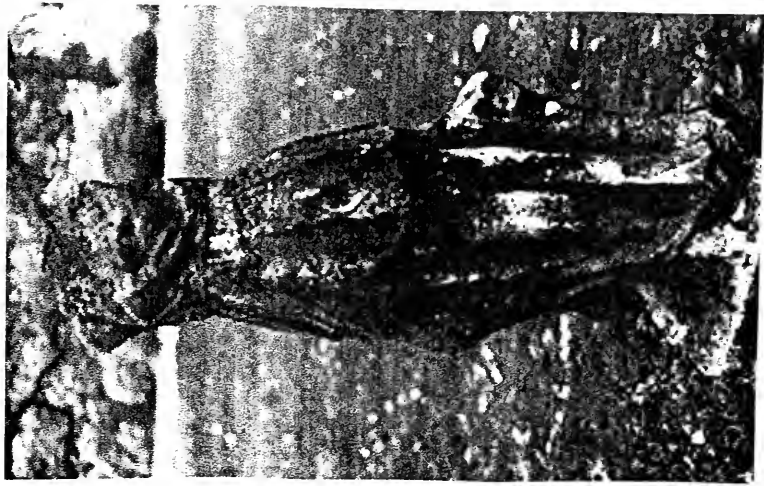
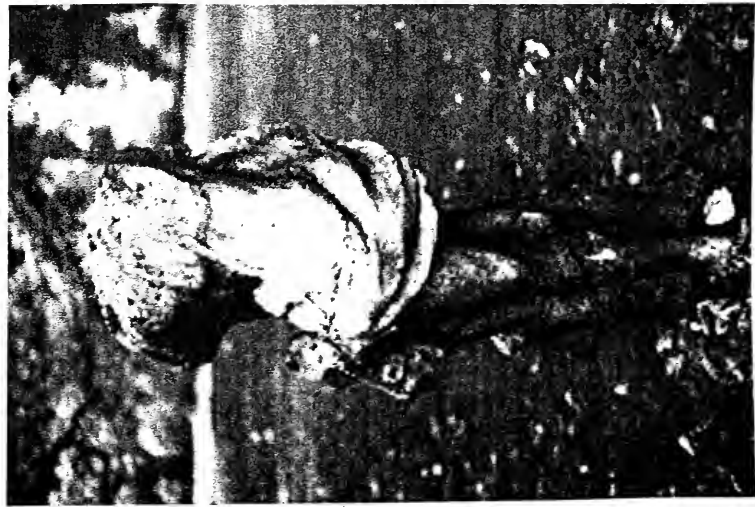


Figure A-3. Female and Male Busts.



Figure A-4. Standing Figure and Torso.



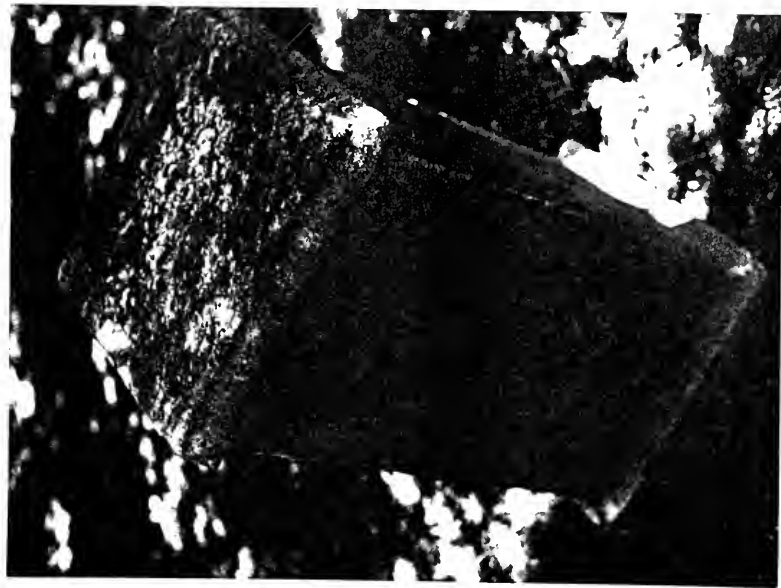
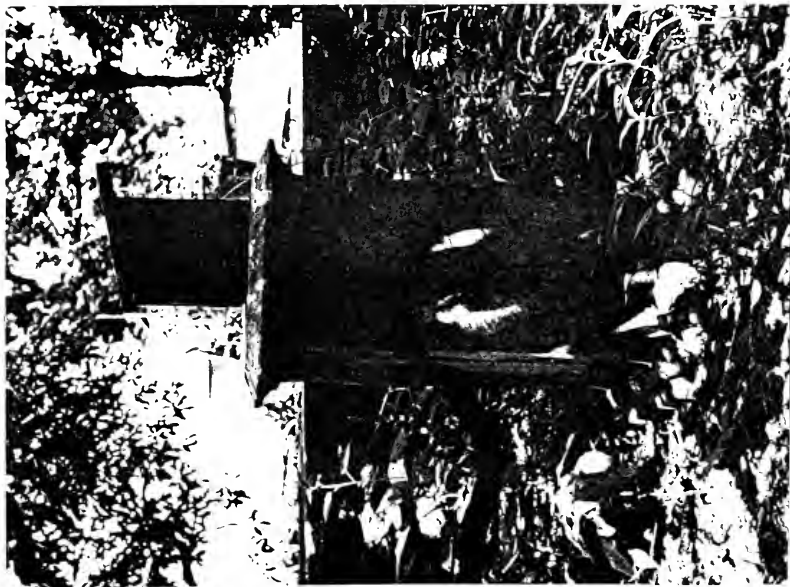


Figure A-6. Small Pedestal and Large Pedestal.

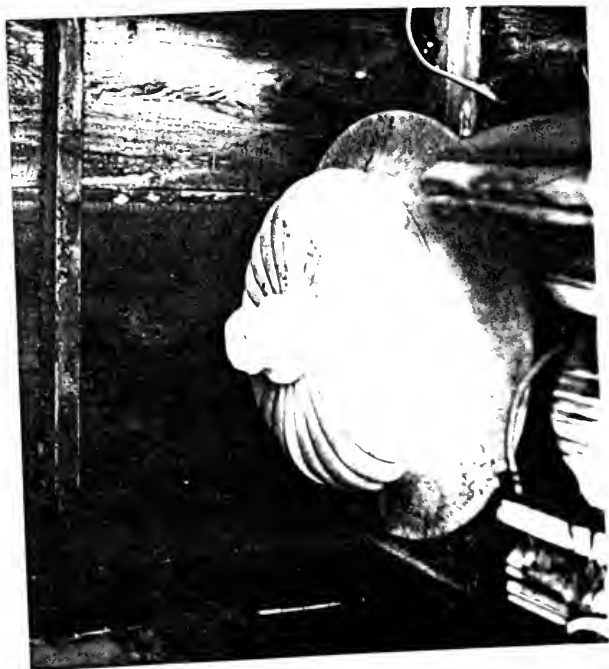
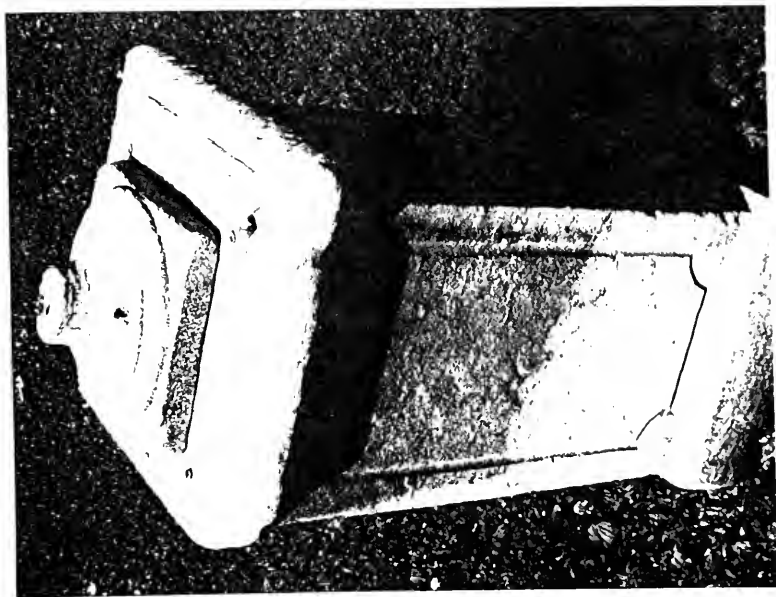


Figure A-7. Urn and Pedestal.

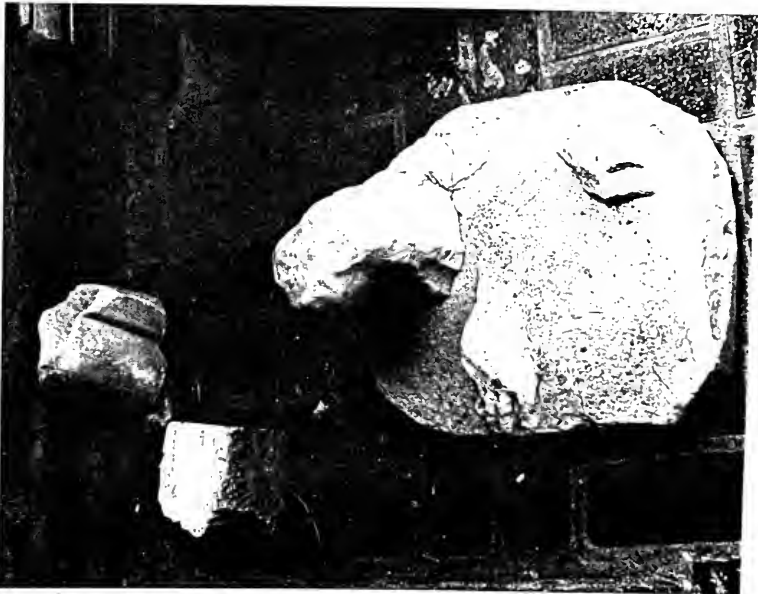


Figure A-8. Base with Feet, and Ball.



Figure A-9. Details of Biological Growth.



Figure A-10. Details of Biological Growth.

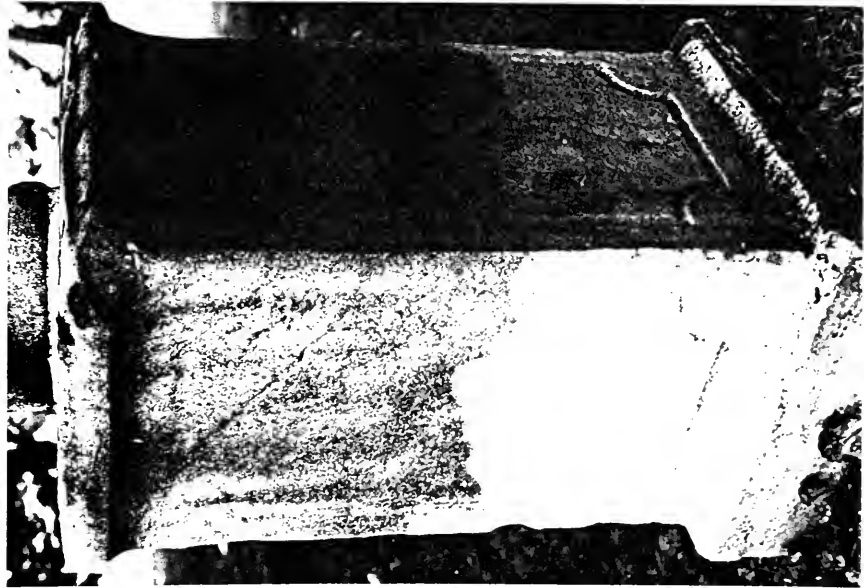


Figure A-11. Details of Biological Growth.

Appendix B - Condition Survey

B-1. Key.

B-2. Lion.

B-3. Lion.

B-4. Female Bust.

B-5. Male Bust.

B-6. Standing Figure.

B-7. Standing Headless Male.

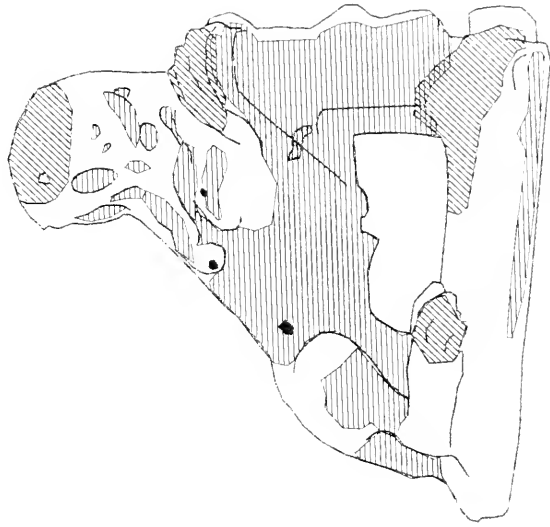
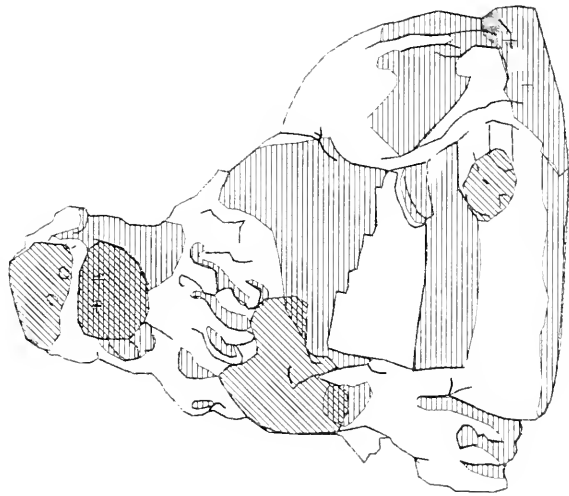
B-8. Standing Headless Female.

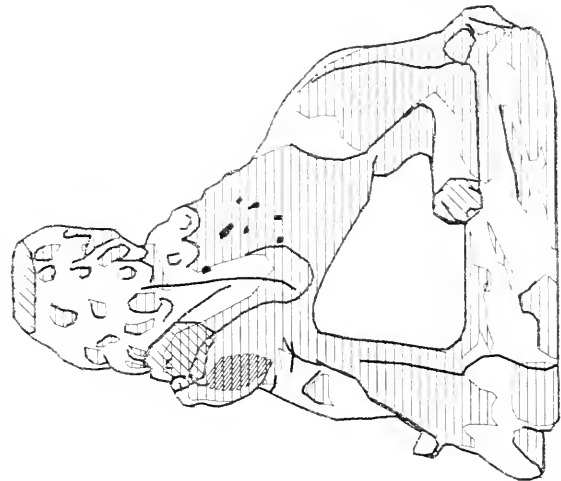
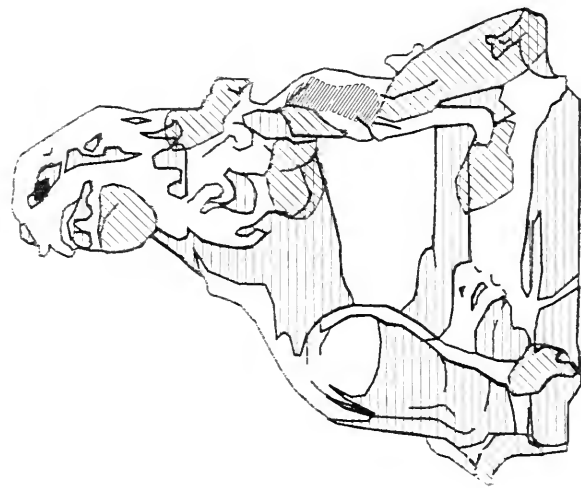
B-9. Pedestal with Urn Base.

B-10. Large Pedestal.



Figure B-1. Key.





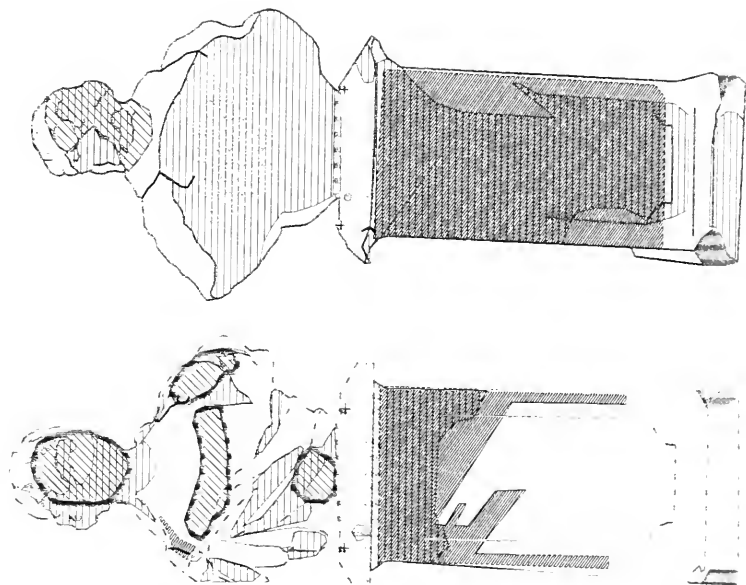


Figure B-4. Female Bust.
Accession No. NT 73.55.4(1).

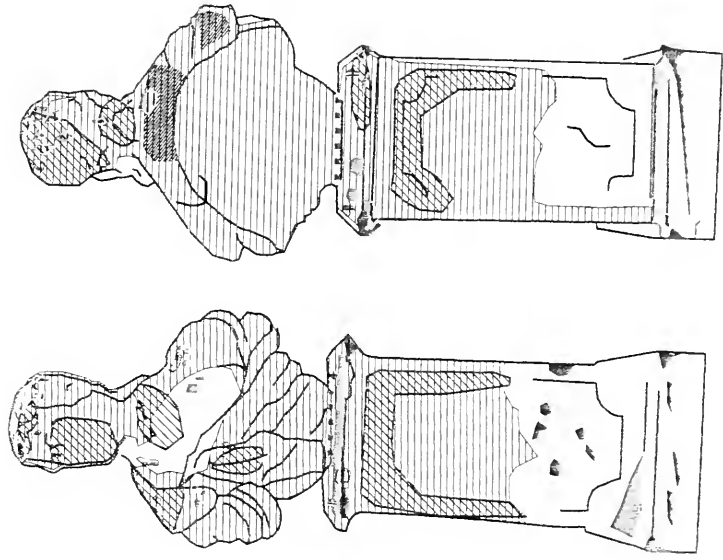


Figure B-5. Male Bust.
Accession No. NT 73.55.4(2).

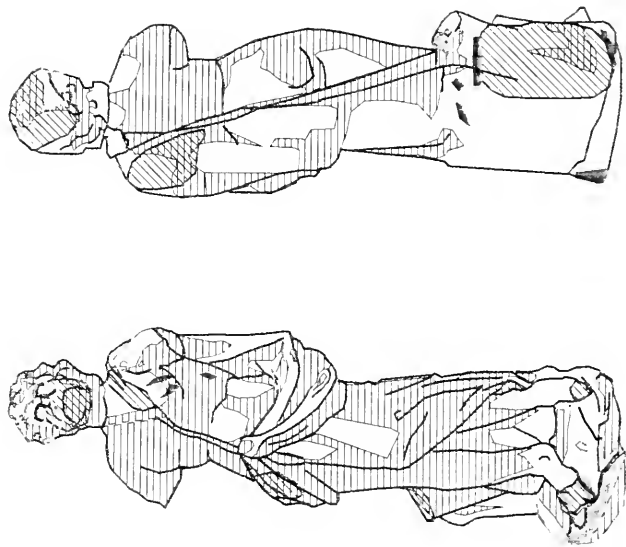


Figure B-6. Standing Figure.
Accession No. NT 73.55.3(2).

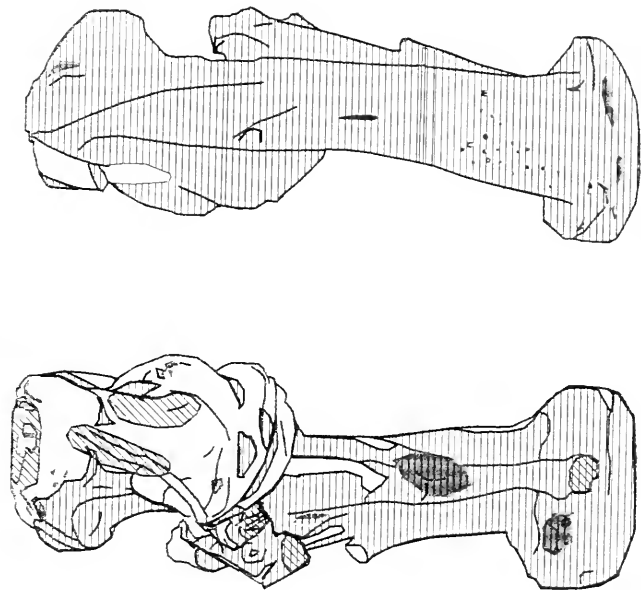


Figure B-7. Standing Headless Male.
Accession No. NT 73.55.3(1).

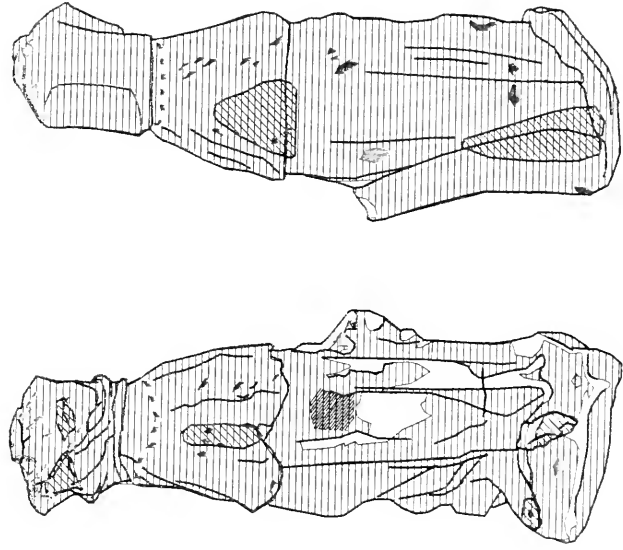


Figure B-8. Standing Headless Female.
Accession No. NT 73.55.3(3).

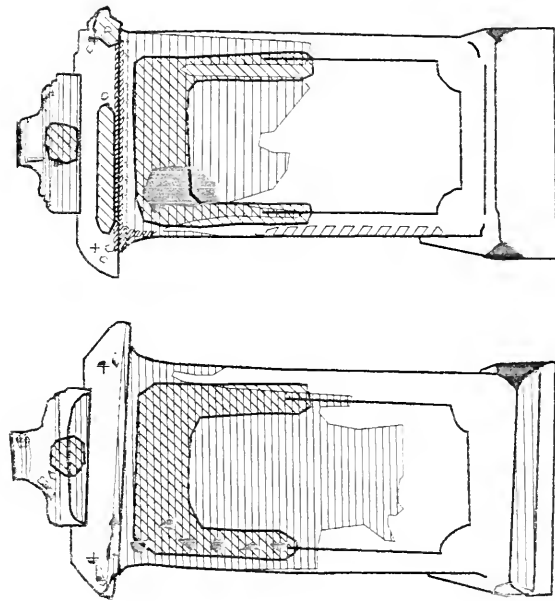


Figure B-9. Pedestal (and Urn base).
Accession No. NT 73.55.2.

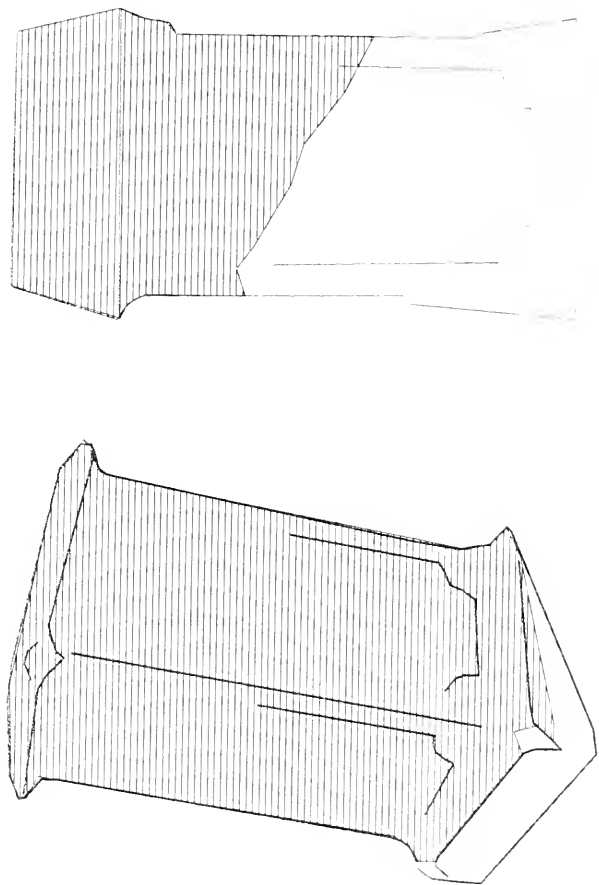


Figure B-10. Large Pedestal.
Accession No. NT 73.55.6(2).

Appendix C - Registered Products

<u>Chemical Name & Active Ingredient (Common Name)</u>	<u>Product Names</u>	<u>Manufacturer</u>
TOLUIC ACID, 6-(4-ISOPROPYL-4-METHYL-5-OXO-2-IMIDAZOLIN-2-YL)-, METHYL ESTER AC 222,293	Assert Herbicide Assert Herbicide Technical Assert SG Herbicide	American Cyanamid Co American Cyanamid Co American Cyanamid Co
2'-ETHYL-6'-METHYL-N-(ETHOXYMETHYL)-2-CHLOROACETANILIDE Acetochlor	MON 8421 Herbicide MON 8407 Herbicide Harness Plus Herbicide Harness Xtra Tophand Grass Herbicide MON 8434 Herbicide Harness 20 G Herbicide MON 8411 Herbicide MON 8413 Herbicide MON 58420 Herbicide Surpass EC Herbicide Surpass 100 Selective Herbicide Doubleplay Selective Herbicide Topnotch No Till Herbicide Surpass 20-G Granular Herbicide ICIA5676 CS/Atrazine Herbicide Acetochlor Technical Acetochlor EC Herbicide	Monsanto Ag Co Monsanto Ag Co Monsanto Ag Co Monsanto Ag Co Monsanto Ag Co Monsanto Ag Co Monsanto Ag Co Monsanto Ag Co Monsanto Ag Co Monsanto Ag Co Monsanto Ag Co Monsanto Ag Co Zeneca AG Products Zeneca AG Products Zeneca AG Products Zeneca AG Products Zeneca AG Products Zeneca AG Products Zeneca AG Products
AMPELOMYCES QUISQUALIS ISOLATE M-10 Ampelomyces Quisqualis	AQ-10 Biofungicide	Ecogen Inc
ALPHA-CYCLOPROPYL-ALPHA-(4-METHOXYPHENYL)-5-PYRIDINEMETHANOL Ancymicol	A-Rest Solution A-Rest Technical	Sepro Corp Sepro Corp

METHYL SULFANILYLCARBAMATE

Asulam

Asulam Technical

Rhone-Poulenc AG Co

BACILLUS SUBTILIS MBI 600

Bacillus Subtilis

Epic Biological Fungicide

Gustafson Inc

BARIUM METABORATE

Barium Metaborate

Busan 11-M1

Buckman Laboratories Inc
Foster Products Corp

2,2'-(1-METHYLTRIMETHYLENEDIOXY)BIS(4-METHYL-1,3,2-DIOXABORINANE)

Biobor

Diesel Sta-Bil
Biobor JF

Gold Eagle Co
Hammonds Fuel Additives Inc

5-BROMO-3-SEC-BUTYL-6-METHYLURACIL

Bromacil

Riverdale 1% Bromacil Granular Weed Killer
Riverdale 2% Bromacil Granular Weed Killer
Riverdale 2.5% Bromacil Liquid RTU Weed Killer
Dupont Bromacil Technical

Riverdale Chemical Co
Riverdale Chemical Co
Riverdale Chemical Co

10% Bromacil Pellets Weed Killer
Dupont 80% Bromacil Powder

Dupont De Nemours & Co Inc
Dupont De Nemours & Co Inc

4% Bromacil Granular Weed Killer
Dupont 21.9% Bromacil Liquid Concentrate

Dupont De Nemours & Co Inc
Dupont De Nemours & Co Inc

7.5% Bromacil Liquid Concentrate
2.5% Bromacil Liquid Weed Killer

Dupont De Nemours & Co Inc
Dupont De Nemours & Co Inc

2% Bromacil Liquid Weed Killer
Setre Simazine-Bromacil 90W P

Dupont De Nemours & Co Inc
Helena Chemical Co

Hi-Yield 7.5% Bromacil Liquid Concentrate
Hi-Yield 2.5% Bromacil Liquid Weed Killer

Voluntary Purchasing Group Inc
Voluntary Purchasing Group Inc

Stakill Diuron and Bromacil Weed Killer
Hykill Bromacil 10G

Industrial Weed Killers Inc
Corn Belt Chemical Co

Bromacil 4G Granular Weed Killer
Two Plus Two Bromacil and Diuron

Corn Belt Chemical Co
Corn Belt Chemical Co

Four Plus Four Bromacil and Diuron
Chapman Bromacil 8P

Corn Belt Chemical Co
Drexel Chemical Co

Chapman Bromacil 4P

Drexel Chemical Co

2-BROMO-2-NITROPROPANE-1,3-DIOL Bronopol	Clean Crop Bromacil Weed Killer Hopkins 10% Bromacil Pellets 12.5% Water Soluble Bromacil Liquid Weed Killer	Platte Chemical Co Inc Platte Chemical Co Inc R&M Regulatory Services
	Slimicide DE 1220 Slimicide C-84 Betz DE-5556 Biocide M-95 Slime-Trol DPB-1296 Bronopol Preservative Bioban 2001 Antimicrobial Agent Myacide AS Plus Myacide S-2 Myacide S-1 Myacide S-15 Myacide BT BBJ Microbiocide EC9086A	Betzdearborn Inc Betzdearborn Inc Betzdearborn Inc Petroliite Corp Paper Process Group Inc Angus Chemical Co Angus Chemical Co Angus Chemical Co Angus Chemical Co Angus Chemical Co Angus Chemical Co Angus Chemical Co BBJ Chemical Compounds Inc Nalco/Exxon Energy Chemicals LP
5-ETHYL DIISOBUTYL THIOCARBAMATE Butylate	Sutan +6.7-E Selective Herbicide Sutan Technical BRC605 6.7E Selective Herbicide Clean Crop Butylate 6.7EC Sutan +6.7E	Zeneca AG Products Zeneca AG Products Zeneca AG Products Platte Chemical Co Inc Micro-Flo Co
3-PYRIDINECARBOXYLIC ACID, 2-(4,5-DIHYDRO-4-METHYL-4-(1-METHYLETHYL)-5-OXO-1H-IMIDAZOL-2-YL)-5-METHYL- Cadre	Cadre Herbicide AC 263,222 Herbicide	American Cyanamid Co American Cyanamid Co
CANDIDA OLEOPHILA ISOLATE I-182 Candida Oleophila	Aspire Biofungicide	Ecogen Inc
CHLORHEXIDINE DIACETATE Chlorhexidine diacetate	Nolvasan Solution	Fort Dodge Laboratories

Nolvasan S	Fort Dodge Laboratories
Chlorhexidine Acetate	Fort Dodge Laboratories
2-[[4-CHLORO-6-(ETHYLAMINO)-S-TRIAZIN-2-YL]AMINO] Cyanazine	
Dupont Bladex 4L Herbicide	Dupont De Nemours & Co Inc
Dupont Cyanazine Technical	Dupont De Nemours & Co Inc
Dupont Bladex 90DF Herbicide	Dupont De Nemours & Co Inc
Dupont Extrazine II 4L Herbicide	Dupont De Nemours & Co Inc
Dupont Extrazine II DF Herbicide	Dupont De Nemours & Co Inc
Cyanazine Technical	Griffin Corp
Cynex DF	Griffin Corp
Cynex 4L	Griffin Corp
Cynex Extra 4L	Griffin Corp
Cynex Extra DF	Griffin Corp
ALPHA-(4-CHLOROPHENYL)-ALPHA-(1-CYCLOPROPYLETHYL)-1H-1,2,4-TRIAZOLE-1-ETHANOL Cyproconazole	Sandoz Agro Inc
	Sandoz Agro Inc
BUTANEDIOIC ACID MONO(2,2-DIMETHYLLHYDRAZIDE) Daminozide	
ALAR-85	Uniroyal Chemical Co Inc
B-Nine SP	Uniroyal Chemical Co Inc
ALAR Technical	Uniroyal Chemical Co Inc
ETHYL M-HYDROXYCARBANILATE CARBANILATE Desmedipham	
Desmedipham Technical	AgrEvo USA Co
Betanex	AgrEvo USA Co
Betanex Herbicide	AgrEvo USA Co
Betanex 70 WP	AgrEvo USA Co
Betanex 70WP	AgrEvo USA Co
NA 305	AgrEvo USA Co
Betanex Progress	AgrEvo USA Co
CQ 1451	AgrEvo USA Co
NA 307	AgrEvo USA Co

2,6-DIMETHYL-M-DIOXAN-4-OL ACETATE

Dimethoxane

Giv-Gard DXN

Givaudan-Roure Corp

3,5-PYRIDINEDICARBOETHIOIC ACID, 2-(DIFLUOROMETHYL)-4-(2-METHYLPROPYL)-6-(TRIFLUOROMETHYL)-, S,S-DIMETHYL ESTER

Dithiopyr

Mon 15100 Herbicide

Dimension Turf Herbicide

Dimension 1EC Turf Herbicide

Dimension 2 FG Turf Herbicide

Dimension 0.25 G Turf Herbicide

Dimension 80 Turf Herbicide w/Plant Food

Dimension 100 Turf Herbicide w/Plant Food

Dimension 170 Turf Herbicide w/Plant Food

Dimension 250 Turf Herbicide w/Plant Food

The Andersons Dimension Herbicide IV

The Andersons Dimension Herbicide I

The Andersons Dimension Herbicide II

The Andersons Dimension Herbicide III

Lange Brand Dimension Granules Turf Herbicide

Rohm & Haas Co

Rohm & Haas Co

Rohm & Haas Co

Rohm & Haas Co

Rohm & Haas Co

Knox Fertilizer Co Inc

Knox Fertilizer Co Inc

Knox Fertilizer Co Inc

Knox Fertilizer Co Inc

Andersons, Lawn Fertilizer Div

Andersons, Lawn Fertilizer Div

Andersons, Lawn Fertilizer Div

Andersons, Lawn Fertilizer Div

Lange-Stegmann Fertilizer Co

6,7-DIHYDRODIPYRIDO(1,2-A:2',1'-C)PYRAZINEDIIUM DIBROMIDE

Diquat Dibromide

Real-Kill Vegetation Killer

Weedtrine D Aquatic Herbicide

Contact Herbicide #1 Non-Selective

Diquat Herbicide

Diquat Concentrate

Reward Aquatic and Noncrop Herbicide

Realex

Applied Biochemists

Athea Laboratories Inc

Zeneca AG Products

Zeneca AG Products

Zeneca AG Products

N-ETHYL-N-(2-METHYL-2-PROPENYL)-2,6-DINITRO-4-(TRIFLUOROMETHYL)- BENZENAMINE

Ethalfuralin

Clean Crop Curbit EC Herbicide

Ethalfuralin Technical

Sonalan 10G

Sonalan HFP

Technical Ethalfuralin

Platte Chemical Co Inc

DowElanco

DowElanco

DowElanco

Dintec Agrichemicals

ETHYLENE

Ethylene

Ethylene Agricultural Grade

Banana Gas-32

Flavor Fresh Ethylene

Ethylene

Livingston's Tobacco Curing Gas

Livingston's Nature-Ripe TM

Ban-Gas

Technical Ethylene

Color Ripe/Witchaway

Ethylene

Ethylene Compressed Plant Growth Regulator

Praxair Inc

Praxair Inc

Praxair Inc

Air Products & Chemicals Inc

Livingston Chemicals Inc

Livingston Chemicals Inc

Livingston Chemicals Inc

Pernviro Systems Inc

Pernviro Systems Inc

Air Liquide America

George W. Fowler Co

2-CYANO-2-PHENYL-2-(BETAOP-CHLOROPHENETHYL)ETHYL-1H-1,2,4-TRIAZOLE

Fenbuconazole

RH-7592 Technical

Enable 2F

Indar 75 WSP

RH-7592 WP

Rohm & Haas Co

Rohm & Haas Co

Rohm & Haas Co

Rohm & Haas Co

PENTYL 2-CHLORO-4-FLUORO-5-(3,4,5,6-TETRAHYDROPTALIMIDO)PHENOXYACETATE

Flumiclorac Pentyl Ester

Flumiclorac Pentyl Technical

Resource Herbicide

Stellar Herbicide

Valent USA Corp

Valent USA Corp

Valent USA Corp

ALPHA-ISOPROPYL-ALPHA-(P-(TRIFLUOROMETHOXY)PHENYL)-5-PYRIMIDINEMETHANOL

Flurprimidol

Cutless 50W Turf Plant Growth Regulator

Cutless TP

Cutless 10W

Turf Fertilizer

Cutless 0.33G

DowElanco

DowElanco

DowElanco

DowElanco

DowElanco

AMMONIUM ETHYL CARBAMOYLPHOSPHONATE

Fosamine Ammonium

Dupont Krenite S Brush Control Agent

Dupont De Nemours & Co Inc

GIBBERELLIC ACID
Gibberellic Acid

Provide Plant Growth Regulator Solution
Pro-Gibb Plus 2X Plant Growth Regulator
Promalin Plant Growth Regulator Solution
Release LC Plant Growth Regulator Solution

Abbott Laboratories
Abbott Laboratories
Abbott Laboratories
Abbott Laboratories

GLIOCLADIUM VIRENS G-21
Gliocladium virens

WRC-AP-1
WRC-GL-21

Thermo Trilogy Corp
Thermo Trilogy Corp

N-(PHOSPHONOMETHYL)GLYCINE
Glyphosate

Glyphosate
Dynasty Herbicide
ETK-2301 Herbicide

Monsanto Ag Co
Zeneca AG Products
Entek Corp

3-CHLORO-5-(((4,6-DIMETHOXY-2-PYRIMIDINYL)AMINO)CARBONYL)AMINO)SULFONYL)-1-METHYL-1H-PYRAZOLE-4-CARBOXYLIC ACID, METHYL ESTER
Halosulfuron

Permit Herbicide
Battalion Herbicide
Mon 12000 Herbicide
Manage Herbicide

Monsanto Ag Co
Monsanto Ag Co
Monsanto Ag Co
Monsanto Ag Co

3-CYCLOHEXYL-6-(DIMETHYLAMINO)-1-METHYL-1,3,5-TRIAZINE-2,4-(1H,3H)-DIONE
Hexazinone

Riverdale 1.25% Hexazinone Liquid
Dupont Velpar Herbicide
Dupont Velpar L Herbicide
Dupont Hexazinone Technical
Dupont Velpar ULW Herbicide
Velpar DF Herbicide
Velpar ULW DF Herbicide
Pronone 10G
Pronone Power Pellet Herbicide
Pronone 25G
Fiscan Plugs Selective Injection Herbicide

Riverdale Chemical Co
Dupont De Nemours & Co Inc
Dupont De Nemours & Co Inc
Dupont De Nemours & Co Inc
Dupont De Nemours & Co Inc
Dupont De Nemours & Co Inc
Dupont De Nemours & Co Inc
Pro Serve Inc
Pro Serve Inc
Pro Serve Inc
Forestry Injection Co Fic AB

INDOLE-3-BUTYRIC ACID

Indole-3-Butyric Acid

Hormo Root A
Hormex Rooting Powder No. 1
Maxon II
Wood's Rooting Compound
Indole-3-Butyric Acid Technical
PGR-IV Concentrate

Rockland Corp
Brooker Chemical Corp
Riverside/Terra Corp
Earth Science Products Corp
Micro-Flo Co
Micro-Flo Co

N-(3-(1-ETHYL-1-METHYLPROPYL)-5-ISOXAZOLYL)-2,6-DIMETHOXYBENZAMIDE

Isoxaben

Gallery Technical 91%
Gallery 75 Dry Flowable
Snapshot 80 DF
Snapshot 2.5 TG

DowElanco
DowElanco
DowElanco
DowElanco

LACTIC ACID

Lactic acid

Bio Savor
Propel Plant Growth Regulator

Kemin Industries Inc
Entek Corp

3-(3,4-DICHLOROPHENYL)-1-METHOXY-1-METHYLUREA

Linuron

Dupont Linuron Flake Technical
Dupont Lorox DF Herbicide
Linex 4L
Griffin Linuron Technical
Linex 50 DF
Atrazine Plus Linuron
Linuron 4L Weed Killer
Linuron Flake Technical
Drexel Linuron DF
Linuron Technical I
Technical Linuron II
Clean Crop Linuron 4L Herbicide
Linuron 4L Weed Killer

Dupont De Nemours & Co Inc
Dupont De Nemours & Co Inc
Griffin Corp
Griffin Corp
Griffin Corp
Drexel Chemical Co
Drexel Chemical Co
Drexel Chemical Co
Drexel Chemical Co
Drexel Chemical Co
Drexel Chemical Co
Platte Chemical Co Inc
Micro-Flo Co

LITHIUM HYPOCHLORITE

Lithium Hypochlorite

Olin 65% Lithium Hypochlorite
Jolt Pool Shock Treatment for Control of Algae

Olin Corp
Qualco Inc

ALPHA-BUTYL-ALPHA-(4-CHLOROPHENYL)-1H-1,2,4-TRIAZOLE-1-PROPANENITRILE

Myclobutanil

RH-3866 Technical
Rally 60 DF Fungicide
Rally 40W Ag Fungicide
Nova 40 W Ag Fungicide
Nu-Flow M Seed Treatment Fungicide
Eagle WSP Fungicide
Systane WSP Ornamental Fungicide

DISODIUM ETHYLENEBIS(DITHIOCARBAMATE)

Nabam

AMA-31
AMA-30
AMA-9
Aquatreat DNM-30
Aquatreat DN-30
Aquatreat DNM-9
Aquatreat DNM-360
Aquatreat DNM-25E
Aquatreat DNM-80
Amersperse 280

Vinings Industries Inc
Vinings Industries Inc
Vinings Industries Inc
National Starch & Chemical Co
National Starch & Chemical Co
National Starch & Chemical Co
National Starch & Chemical Co
National Starch & Chemical Co
National Starch & Chemical Co
Ashland Chemical Co

FATS AND GLUCERIDIC OILS, MARGOSA

Neem Oil

Neem Oil TGA
Neemguard
Neem Oil RTU

Thermo Trilogy Corp
Thermo Trilogy Corp
Thermo Trilogy Corp

2-((((4,6-DIMETHOXY-2-PYRIMIDINYL)AMINO)CARBONYL)AMINO)SULFONYL)-N,N-DIMETHYL-3-PYRIDINECABOXAMIDE

Nicosulfuron

Dupont Nicosulfuron Technical
Dupont Accent SP Herbicide
Dupont DPX-79406 75 DF Herbicide
Basis Gold SP

Dupont De Nemours & Co Inc
Dupont De Nemours & Co Inc
Dupont De Nemours & Co Inc
Dupont De Nemours & Co Inc

4-CHLORO-5-(METHYLAMINO)-2-(ALPHA,ALPHA,ALPHA-TRIFLUORO-M-TOLYL)-3(2H)-PYRIDAZINONE

Norflurazon

Technical Norflurazon
Evital
Zorial Rapid 80

Sandoz Agro Inc
Sandoz Agro Inc
Sandoz Agro Inc

OXYBISPHENOXARSINE OBPA	Sollicam DF Herbicide Boundary DF Herbicide	Sandoz Agro Inc Sandoz Agro Inc
	Vinyzene BP-5 Durotex 7603 Vinyzene BP-5-2 Vinyzene BP-5SIL3 Vinyzene BP-5-2MS Vinyzene BP-5-2 MEK Vinyzene SB-1 OBPA Vinyzene BP-505 DIDP Vinyzene RP 1000 Vinyzene SB-2 Pollicida P-4 OBPA (10,10' Oxybisphenoxarsine) Defunge-5 OBPA Intericide ABF-2 DOP Intericide ABF-5 DIDP	Morton International Inc Morton International Inc Morton International Inc Morton International Inc Morton International Inc Morton International Inc Morton International Inc Morton International Inc Morton International Inc Morton International Inc Azko Nobel Chemicals Inc Burlington Scientific Corp Burlington Scientific Corp Akros Chemicals America Akros Chemicals America
3,5-DINITRO-N',N'-DIPROPYL SULFANILAMIDE Oryzalin	Expedite Grass & Weed Plus Herbicide Turf Pride with .5% Surflan Pre-Emergence Herb. Rout Ornamental Herbicide Surflan 75W Manuf. Use Herbicide	Monsanto Ag Co Howard Fertilizer Co Inc Scotts-Sierra Crop Protection Co DowEianco
OXADIXYL Oxadixyl	Anchor Flowable Fungicide Oxadixl Technical Fungicide Sandotan 31F Fungicide	Gustafson Inc Sandoz Agro Inc Sandoz Agro Inc
1,1'-DIMETHYL-4,4'-BIPYRIDINIUM DICHLORIDE Paraquat Dichloride	Gramoxone Super Herbicide Cyclone Herbicide Ortho Paraquat Concentrate 3	Zeneca AG Products Zeneca AG Products Zeneca AG Products

NONANOIC ACID	Surefire Herbicide Gramoxone Extra Herbicide Paraquat Concentrate ES Cyclone Concentrate	Zeneca AG Products Zeneca AG Products Zeneca AG Products Zeneca AG Products
Pelargonic acid	Econosan Acid Sanitizer West Agro Acid Sanitizer Soythe Herbicide	West Agro Inc West Agro Inc Mycogen Corp
4-AMINO-3,5,6-TRICHLOROPICOLINIC ACID	Picloram Technical	DowElanco
3-(2-METHYLPIPERIDINO)PROPYL 3,4-DICHLORO BENZOATE	Pipron L.C. Pipron Technical	Sepro Corp Sepro Corp
CARBONIC ACID, MONOPOTASSIUM SALT	Armcarb Potassium Bicarbonate, FCC	Church & Dwight Co Inc
POTASSIUM BROMIDE	Sat-Sol Brand	Diversey Corp
METHYL 2-(((((4,6-BIS(DIFLUOROMETHOXY)-2-PYRIMIDINYL)AMINO)CARBONYLAMINO)SULFONYL)BENZOATE	Beacon Herbicide CGA-136872 Technical Exceed Herbicide	Novartis Crop Protection Inc Novartis Crop Protection Inc Novartis Crop Protection Inc
2,4-DINITRO-N,N'-DIPROPYL-6-(TRIFLUOROMETHYL)-1,3-BENZENEDIAMINE	The Andersons Barricade Herbicide I Lesco Fertilizer w/0.20% Barricade Preemerg. Herb. Barricade T Herbicide Barricade 65WG Herbicide Barricade F Herbicide Barricade MC Herbicide Barricade G Herbicide	Andersons, Lawn Fertilizer Div Lesco Inc. Sandoz Agro Inc Sandoz Agro Inc Sandoz Agro Inc Sandoz Agro Inc Sandoz Agro Inc
Prodiamine		

2,4-BIS[(ISOPROPYLAMINO)-6-(METHYLTHIO)-S-TRIAZINE

Prometryn

Caparol & MSMA w/Surfactant Herbicide

Technical Prometryn

Caparol 4L Herbicide

Caparol Accu-Pak

Cotton-Pro Flowable Herbicide

Cotton Pro 80DF

Prometryne 4L Herbicide

Prometryn + MSMA

Gowan Prometryne 4L

Prometryne 4L Herbicide

Prometryne Technical

2-METHYL-4,5-TRIMETHYLENE-4-ISOTHIAZOLIN-3-ONE

Promexal

Promexal X50 Preservative

3,5-DICHLORO(N-1,1-DIMETHYL-2-PROPYNYL)BENZAMIDE

Pronamide

Kerb 50-W Selective Herbicide

Kerb Technical

Kerb 50W Herbicide in WSP

Green Up Kerb 50W

PROPIONIC ACID

Propionic Acid and Salts

Econosan Acid Sanitizer

West Agro Acid Sanitizer

Luprosil

Kem Prop Liquid

Grain Savor

Kem San

Tenox P-RF Preservative

Tenox P Grain Preservative

Union Carbide Propionic Acid

Propionic Acid

Propionic Acid

Clean Crop Grain Preserver

P-7 Grain Preservative

Novartis Crop Protection Inc

Novartis Crop Protection Inc

Novartis Crop Protection Inc

Novartis Crop Protection Inc

Griffin Corp

Griffin Corp

Riverside/Terra Corp

Riverside/Terra Corp

Gowan Co

Platte Chemical Co Inc

Verolit Chemical Mfr Ltd

Zeneca AG Products

Rohm & Haas Co

Rohm & Haas Co

Rohm & Haas Co

Pursell Industries Inc

West Agro Inc

West Agro Inc

BASF Corp

Kemin Industries Inc

Kemin Industries Inc

Kemin Industries Inc

Eastman Chemical Co

Eastman Chemical Co

Union Carbide Corp

Hoechst Celanese Chemical Group

BP Chemicals Inc

Platte Chemicals Co Inc

Nayfa Industries Inc

<i>PSEUDOMONAS FLUORESCENS</i> EG-1053 Pseudomonas fluorescens	DMX-7 Mold Inhibitor DMX-7 Plus Lecithin Alfa-Save	Delist Inc Delist Inc Alltech Inc
<i>PSEUDOMONAS SYRINGAE</i> Pseudomonas Syringae, ESC 10	Dagger G Biofungicide	Ecogen Inc
<i>PSEUDOMONAS SYRINGAE, STRAIN ESC 11</i> Pseudomonas Syringae, ESC 11	Bio-Save 100 Biological Fungicide ESC-10 Biofungicide Technical Bio-Save 10 Biological Fungicide ESC-11 Biofungicide Technical	Ecoscience Produce Systems Div Ecoscience Produce Systems Div Ecoscience Produce Systems Div Ecoscience Produce Systems Div
<i>PUCCINIA CANALICULATE (SCHWEINITZ) LAGERHEIM</i> Puccinia Canaliculate Lagerheim	Bio-Save 110 Biological Fungicide Bio-Save 11 Biological Fungicide Dr. Biosedge	Ecoscience Produce Systems Div Ecoscience Produce Systems Div
<i>SODIUM 2-CHLORO-6-(4,6-DIMETHOXYPYRIMIDIN-2-YL)AMINOCARBONYL)-3-(ETHYLSULFONYL)-2-PYRIDINESULFONAMIDE</i> Pyriothiac-sodium	Dupont KIH-2031 (DPX-PE350) Technical Dupont Staple Herbicide	Tifton Innovation Corp Dupont De Nemours & Co Inc Dupont De Nemours & Co Inc
<i>SODIUM BICARBONATE</i> Sodium Bicarbonate	Dupont Rimsulfuron Technical Dupont Matrix Herbicide Dupont DPX-E9636 DF Herbicide Dupont Basis Herbicide Dupont DPX-79406 75 DF Herbicide Basis Gold Sp Armcarb Sodium Bicarbonate, FCC	Dupont De Nemours & Co Inc Dupont De Nemours & Co Inc Dupont De Nemours & Co Inc Dupont De Nemours & Co Inc Dupont De Nemours & Co Inc Dupont De Nemours & Co Inc Church & Dwight Co Inc

1-HYDROXY-2-(1H)-PYRIDIMETHIONE, SODIUM SALT

Sodium Omdadine

Sodium Omdadine 40% Aqueous Solution Ind.
Triadine 10 Bactericide-Fungicide Ind. Microbiostat
Triadine 20 Industrial Microbiostat
Sodium Omdadine 10% Aqueous Solution Ind.

Olin Corp
Olin Corp
Olin Corp
Olin Corp

STREPTOMYCIN A

Streptomycin

Streptomycin 3000 Dust

Repar Corp

TRIMETHYLSULFONIUM CARBOXYMETHYLAMINOMETHYLPHOSPHONATE

Sulfosate

Touchdown Concentrate Herbicide
Touchdown 4-LC
Touchdown Technical
Touchdown Herbicide

Zeneca Ag Products
Zeneca Ag Products
Zeneca Ag Products
Zeneca Ag Products

SULFUR

Sulfur

Bonide Sulphur Plant Fungicide

Kocide 404S Flowable Agricultural Fungicide

Wettable Sulfur Agricultural Insecticide-Fungicide

Apple and Peach Koloform Fungicide

Kolodust 60 Fungicide-Miticide

Wettable Sulfur Fungicide-Insecticide

Dusting Sulfur Fungicide-Insecticide

Safer Garden Fungicide Ready to Use

Safer Garden Fungicide Concentrate

Flowable Sulfur 52% Fungicide-Miticide

Bonide Products Inc
Griffin Corp
AMVAC Chemical Corp
Platte Chemical Co Inc
Platte Chemical Co Inc
Platte Chemical Co Inc
Safer Inc
Safer Inc
Fertilizer Corp of America

SULFURYL FLUORIDE

Sulfuryl Fluoride

Vikane Gas Fumigant

DowElanco

1H-1,2,4-TRIAZOLE-1-ETHANOL, .ALPHA.-(2-(4-CHLOROPHENYL)ETHYL)-.ALPHA.-(1,1-DIMETHYLETHYL)-.(+/-),

Tebuconazole

Folicur Technical

Elite 45 DF Foliar Fungicide

Raxil 0.26 FS

Raxil 2.6FS

Folicur 3.6F Foliar Fungicide

Bayer Corp
Bayer Corp
Bayer Corp
Bayer Corp
Bayer Corp

Gustafson Inc
Gustafson Inc
Gustafson Inc

Raxil Thiram Flowable Fungicide
Raxil 0.26 FS Seed Treatment Fungicide
Raxil 2.6 Seed Treatment Fungicide

1,3-BIS(4-ETHOXY-4'-VINYLBIPHENYL)-4,4'-THIADIAZOLE-2-VINYL-N,N'-DIMETHYLUREA

Tebuthiuron

Rainbow Technology Corp
Rainbow Technology Corp
SSI Mobley Co Inc
SSI Mobley Co Inc

DowElanco
DowElanco
DowElanco
DowElanco

Spike 80W
Spike Technical
Spike 20P
Spike 40P

3-ETHYL BUTYL AMINO-4-CHLORO-6-ETHYL AMINO-S-TRIAZINE

Terbutylazine

FMC Corp, Ag Products Group
FMC Corp, Ag Products Group
FMC Corp, Ag Products Group
Vining Industries Inc

4,5,6-Triazin-2-ylamino(sulfonyl)-2-thiophenecarboxylate

Thiameturon methyl

Dupont Pinnacle Herbicide
Dupont Pinnacle Herbicide
Dupont DPX-M6316 Technical Herbicide
Harmony Extra Herbicide
Dupont Pinnacle Agrib Herbicide
Dupont Concert SP Herbicide
Dupont Basis Herbicide
Dupont Synchrony STS DF Herbicide
Dupont Synchrony STS SP Herbicide
Dupont Reliance STS SP Herbicide
Dupont Reliance STS Herbicide

3-(6-METHOXY-4-METHYL-1,3,5-TRIAZIN-2-YL)-1-(2-(2-CHLOROETHOXY)PHENYL)SULFONYLUREA		
Triasulfuron	CGA-131036 Technical	Novartis Crop Protection Inc
	Amber Herbicide	Novartis Crop Protection Inc
	Custom-Pak Amber Herbicide	Novartis Crop Protection Inc
METHYL 2-((((4-METHOXY-6-METHYL-1,3,5-TRIAZIN-2-YL)METHYLAMINO)CARBONYL)AMINO)SULFONYLBENZOATE		
Tribenuron methyl	Express Herbicide	Dupont De Nemours & Co Inc
	Dupont DPX-L5300 Technical	Dupont De Nemours & Co Inc
	Harmony Extra Herbicide	Dupont De Nemours & Co Inc
BETA-(4-CHLOROPHENOXY)-ALPHA-((1,1-DIMETHYLETHYL)-1H-1,2,4-TRIAZOLE-1-ETHANOL		
Triadimenol	Wilbur Ellis Baytan Flowable	Wilbur Ellis Co
	Baytan Seed Treatment Fungicide	Bayer Corp
	Baytan Technical	Bayer Corp
	Baytan 2.6 FS Seed Treatment Fungicide	Bayer Corp
	Gustafson RTU-Baytan-Thiram Fungicide	Gustafson Inc
	Gustafson Baytan 30 Fungicide	Gustafson Inc
	Baytan Captan HB Fungicide	Gustafson Inc
1-(1-(4-CHLORO-2-(TRIFLUOROMETHYL)PHENYL)IMINO)-2-PROPOXYETHYL)-1H-IMIDAZOLE		
Triflumizole	Procure 50W	Uniroyal Chemical Co Inc
	Terraguard 50W	Uniroyal Chemical Co Inc
	A815 Technical	Uniroyal Chemical Co Inc
(ALPHA,ALPHA,ALPHA-TRIFLUORO-2,6-DINITRO-N,N-DIPROPYL-P-TOLUIDINE)		
Trifluralin	Tri-Scept Herbicide	American Cyanamid Co
	Passport Herbicide	American Cyanamid Co
	Tri-5 Herbicide	American Cyanamid Co
	Tri-4 A.T. Herbicide	American Cyanamid Co
	Tri-4 Herbicide	American Cyanamid Co
	Tri-4 HF Herbicide	American Cyanamid Co
	Granular Buckle Herbicide	American Cyanamid Co
	Freedom Herbicide	Monsanto Ag Co
	Trifluralin 4EC Herbicide	Monsanto Ag Co
	Trifluralin 4 Liquid Herbicide	Universal Cooperatives Inc
	Salute 4EC Herbicide	Aceto Ag Chemicals Corp
		Bayer Corp

XYLENOL	Verta Green Sprayable Herbicide Tee Time Sprayable Herbicide Pro "1" Pre-Emergence Herbicide	Pursell Industries Inc Andersons, Lawn Fertilizer Div R&M Regulatory Services
Xylenol	Galex	AgBioChem Inc
ZINC BORATE	Borogard ZB	US Borax Inc
Zinc Borate		

<u>Company Name</u>	<u>Address</u>	<u>Phone</u>	<u>Web Site Address</u>
Abbott Laboratories, Chem & Ag Products	1401 Sheridan Rd, D-442, Bldg A1	North Chicago, IL 60064-4000	800/323-9597 www.abbott.com/products/chemical.htm
Aceto Agriculture Chemicals Corp	One Hollow Lane	New Hyde Park, NY 11042-1215	516/627-6000
AgBioChem, Inc	3 Fleetwood Court	Orinda, CA 94563	510/254/0789
AgrEvo USA Co	2711 Centerville Rd	Wilmington, DE 19808	800/441-6138 www.agrevo-usa.com
Air Liquide America	3511 W. 12th St	Houston, TX 77008	713/868-0647
Air Products & Chemicals Inc	7201 Hamilton Blvd	Allentown, PA 18195-1501	610/481-4911 www.airproducts.com
Akros Chemicals America	500 Jersey Ave	New Brunswick, NJ 08903	908/247-2202 www.akros.com
Alco Chemical Div, Natl Starch & Chem Co	909 Mueller Drive	Chattanooga, TN 37406-0401	423/629-1405 www.nationalstarch.com
Altech, Inc	210 Inverness Court Dr	Birmingham, AL 35201	205/969-3400
American Cyanamid Company	1 Campus Dr	Parsippany, NJ 07054	800/327-4645 www.cyanamid.com
AMVAC Chemical Corp	2110 Davie Ave	Commerce, CA 90040-1706	213/526-2388
Andersons, Lawn Fertilizer Div, The	1200 Dussel Dr	Maumee, OH 43537	800/225-2639
Angus Chemical Co	1500 E Lake Cook Rd	Buffalo Grove, IL 60089	708/215-8600
Applied Biochemists, Div of LaPorte Water	6120 W Douglas Ave	Milwaukee, WI 53218	414/464-1200
Aqua Clear Industries Inc	2550 9 th Ave, P.O. Box 387	Watervliet, NY 12189-0387	800/346-CHEM www.aqua-clear.com
Ashland Chemical Co	One Drew Plaza	Boonton, NJ 07005-1924	201/263-7636 www.ashchem.com
Althea Laboratories Inc	P.O. Box 23926	Milwaukee, WI 53223	

Azko Nobel Chemicals Inc	5 Livingstone Ave	Dobbs Ferry, NY 10522-3407	914/674-5568	
BASF Corp. Agricultural Products	26 Davis Dr, P.O. Box 13528	Research Triangle Park, NC 27709	800/874-0081	www.basf.com
Bayer Corp. Agriculture Div	8400 Hawthorn Rd	Kansas City, MO 64120-0013	800/842-8020	www.bayer.com/english/2xxxarb/2500/2500.htm
Betzdearborn Inc	4636 Somerton Rd	Trevose, PA 19053-6783	215/953-5588	
Bonide Products Inc	2 Wurz Ave	Yorkville, NY 13495	315/736-8231	
BP Chemicals, Inc	200 Public Sq	Cleveland, OH 44114-2375	216/586-4141	www.bp.com
Brooker Chemical Corp	11240 Sherman Way	Sun Valley, CA 91352	818/764-8700	
Buckman Laboratories, Inc	1256 North Mclean Blvd	Memphis, TN 38108	901/278-0330	www.buckman.com
Burlington Scientific Corp	222 Sherwood Ave	Farmingdale, NY 11735	516/694-9177	
Church & Dwight Co Inc	469 North Harrison St	Princeton, NJ 08543-5297	609/683-5900	
Corn Belt Chemical Co	P.O. Box 410	McCook, NE 69001	308/345-5057	
Delst, Inc	540 E Jamie St	Le Habra, CA 90631	714/773-9231	
Diversey Corp	46701 Commerce Ctr Dr	Plymouth, MI 48170	313/416-4200	www.dowelanco.com
DowElanco	9330 Zionsville Rd 308/3E	Indianapolis, IN 46268	800/352-6776	
Drexel Chemical Co	P.O. Box 13327, 1700 Channel Ave	Memphis, TN 38113-0327	901/774-4370	
Du Pont De Nemours & Co, Inc.	Barley Mill Plaza, Bldg 10	Wilmington, DE 19880-0038	800/441-7515	www.dupont.com/intermediates/product
Earth Science Products Corp	P.O. Box 327, 23735 Airport Rd	NE Aurora, OR 97002	503/678-1216	www.earthsciencelabs.com

Eastman Chemical Co	P.O. Box 511, 100 N Eastman Rd	Kingsport, TN 37662-5075	423/229-2238	www.eastman.com
Ecogen Inc.	2005 Cabot Blvd West	Langhorne, PA 19047	215/757-1595	
Ecoscience Produce Systems Div	P.O. Box 3228	Orlando, FL 32802	407/872-2224	
Entek Corp	3350 E Brian St	Brea, CA 92822	714/577-8001	
Fertilizer Corp of America	9370 Sunset Dr., #A-240	Miami, FL 33173	305/595-6738	
FMC Corp Agr Products Group	1735 Market St	Philadelphia, PA 19103	215/299-6000	
Fort Dodge Laboratories	P.O. Box 518	Fort Dodge, IA 50501	515/955-6462	
Foster Products Corp	3900 Jackson St NE	Columbia Hgts, MN 55421	800/328-2975	
George W. Fowler Co	150 Tequesta Dr, Ste 205	Tequesta, FL 33469	941/763-5310	
Givaudan-Roure Corp	100 Delawanna Ave	Clifton, NJ 07014	201/365-8000	
Gold Eagle Co	4400 S Kildare	Chicago, IL 60632-4372	773/376-4400	
Gowan Co	2809 Sunnyvale Dr	St. Joseph, MI 44085	616/983-4656	
Gowan Pacific Group, L.C.		Rockland, DE 19732	302/654-6657	
Griffin Corp	P.O. Box 1847, 4190 McLeod Rd	Valdosta, GA 31603-1847	912/249-5934	www.datasys.net/griffin
Gustafson, Inc	P.O. Box 660065	Dallas, TX 75266	800/248-6907	www.gustafson.com
Hammonds Fuel Additives Inc		Houston, TX 77238-8114	800/548-9166	
Haviland Consumer Products Inc	421 Ann St, NW	Grand Rapids, MI 49504-2075	616/361-9772	
Helena Chemical Co	6075 Poplar Ave, Ste 500	Memphis, TN 38119	901/761-0050	www.helenachemical.com
Hoechst Celanese Chemical Group	5200 77 Center Dr, Vanguard Ctr	Charlotte, NC 28217	800/242-6222	
Howard Fertilizer Co Inc	P.O. Box 593800	Orlando, FL 32859-3800	407/855-1841	

Industrial Weed Killers Inc	5104 34 th St	Lubbock, TX 79410	806/799-3673
Iweco Inc	8350 Mosley Rd	Houston, TX 77075	713/926-3166
Kemin Industries Inc	Box 70, 21 Maury St	Des Moines, IA 50301	515/266-2111
Livingston Chemicals Inc	4768 Hermitage Rd	Virginia Beach, VA 23455	757/460-3115
Makhteshim-Agan of North America Inc	551 Fifth Ave, Ste 1100	New York, NY 10176	212/661-9800
Micro-Flo Co	P.O. Box 5948	Lakeland, FL 33807	941/647-3608
Monsanto Agricultural Company	700 Chesterfield Parkway North	St. Louis, MO 63198	314/537-6547 www.monsanto.com
Morton International Inc	150 Andover St	Danvers, MA 01923	508/774-3100 www.mortonintl.com
Nalco/Exxon Energy Chemicals, L.P.	7705 Hwy 90-A	Sugarland, TX 77487-0087	281/263-7000
Nayfa Industries Inc		Dallas, TX 75247-0404	214/630-2280
Novartis Crop Protection Inc		Greensboro, NC 27419-8300	910/632-2838
Olin Corp	120 Long Ridge Rd	Stamford, CT 06904-1355	203/356-2000 www.novartis.com/agri/crop
Permivro Systems Inc	3520 Trotter Dr	Alpharetta, GA 30201	404/679-9800
Petrolite Corp	369 Marshall Ave	St. Louis, MO 63119	
Platte Chemical Co Inc	150 South Main St	Fremont, NE 68025	402/727-8222
Praxair Inc	39 Old Ridgebury Rd, M-1	Danbury, CT 06810-5113	203/794-5946
ProServe Inc	400 East Brooks Rd	Memphis, TN 38109	901/332-7052
Pursell Industries Inc	P.O. Box 540, 201 W 4th St	Sylacauga, AL 35150	800/874-8892
Qualco Inc	225 Passaic St	Passaic, NJ 07055	201/473-1222

R&M Regulatory Services	5145 Forest Run Trace, Ste B	Alpharetta, GA 24504	770/751-1073
Rainbow Technology Corp	261 Cahaba Valley Pky	Pelham, AL 35124-1146	800/637-6047
Realex, Div of United Industries Corp	P.O. Box 15842	St. Louis, MO 63114-0842	314/427-0780
Recreational Water Products Inc	887	Scottsdale, GA 30079	404/378-1761
Repar Corp	4321	Silver Spring, MD 20914	301/384-7290
Rhone-Poulenc AG Co	P.O. Box 12014	Research Triangle Park, NC27709	800/334-9745
Riverdale Chemical Co	425 West 194 th St	Glenwood, IL 60425	800/345-3330
Riverside/Terra Corp	600 Fourth St	Sioux City, IA 51101	712/277-1340
Rockland Corp	809 686 Passaic Ave	West Caldwell, NJ 07007	201/575-1322
Rohm & Haas Company	100 Independence Mall West	Philadelphia, PA 19106-2399	215/592-3000
Safer Inc	9555 James Ave S., Ste 200	Bloomington, MN 55431	612/703-3300
Sandoz Agro Inc	1300 East Touhy Ave	Des Plaines, IL 60018	800/435-TURF
Scotts-Sierra Crop Protection Co	14111 Scottslawn Rd	Marysville, OH 43041	800/543-0006
Sepro Corp	11550 N Meridian St, Ste 180	Carmel, IN 46032-4562	317/580-8281
SSI Mobley Co Inc	1909 N Longview St	Kilgore, TX 75662	903/984-5600
Thermo Trilogy Corporation	7500 Grace Drive	Columbia, MD 21044-4098	410/531-4774
Tifton Innovation Corp	1753	Tifton, GA 31793-1753	912/382-9690
Union Carbide Corp	39 Old Ridgebury Rd	Danbury, CT 06817	203/794-2050
Uniroyal Chemical Co, Inc	Benson Rd	Middlebury, CT 06749	www.mbtaarch.com/projdes/unioncar.html 203/573-2674

Univ of Arkansas	1123 S University Ave, Ste 601	Little Rock, AR 72204	501/575-8412
Universal Cooperatives Inc	P.O. Box 460, 7801 Metro Pkwy	Minneapolis, MN 55440	
Valent USA Corp	1333 N. California Blvd, Ste 600	Walnut Creek, CA 94596	800/624-6094
Verolite Chemical Mfr Ltd	551 Fifth Ave, Ste 1100	New York, NY 10176	212/661-9800 www.lbc.co.il/c884.5.html
Viningas Industries Inc	2303 Cumberland Pkwy	Atlanta, GA 30339-4501	800/347-1542
Vinings Industries Inc	2303 Cumberland Pkwy	Atlanta, GA 30339-4501	800/347-1542
Voluntary Purchasing Group Inc	P.O. Box 460	Bonham, TX 75418	903/583-5501
West Agro Inc	501 Santa Fe St	Kansas City, MO 64153	816/421-0366
Westrade USA Inc	10260 Westheimer, Ste 230	Houston, TX 77042	713/785-0053
Wilbur Ellis Co	191 W Shaw Ave	Fresno, CA 93704	209/226-1811
Zeneca AG Products	1800 Concord Pike	Wilmington, DE 19850-5458	800/759-2500 www.zeneca.com

Surface Measurements (microns)

Stone E - marble		CaCl ₂ O ₂	Ba(OH) ₂	NaOCl	H ₂ O ₂	Control
	1	26.60	26.40	11.30	25.00	16.10
	2	19.20	21.60	26.80	4.50	17.90
	3	24.40	17.80	9.90	2.00	17.20
	4	28.50	25.70	27.80	28.50	27.40
	5	22.40	21.90	24.00	18.40	12.40
	6	27.80	26.00	18.90	14.80	20.10
	7	19.50	19.90	19.90	14.60	20.30
	8	17.60	16.50	25.20	29.10	14.70
	9	15.70	21.90	29.00	26.30	13.70
	10	11.00	29.30	18.70	10.00	17.90
	11	23.70	24.70	30.40	23.80	30.30
	12	20.30	18.90	18.90	13.20	22.00
	13	22.80	13.80	23.70	13.90	11.10
	14	25.60	26.80	28.40	17.30	28.80
	15	21.40	22.60	10.50	14.00	17.80
Avg =		21.77	22.25	21.56	17.03	19.18
Std Dev =		4.75	4.32	6.86	8.24	5.82
Variance =		22.57	18.67	47.08	67.95	33.84
F =		1.50	1.81	1.39	2.01	
No. of readings						
> 30.5 microns		1	0	1	2	1

Calculated F values are compared to the tabulated F value of 2.40 for 14 degrees of freedom, at a 95% Confidence Level.

Surface Measurements (microns)

Stone F - marble		CaCl ₂ O ₂	Ba(OH) ₂	NaOCl	H ₂ O ₂	Control
1	20.90	13.10	4.60	22.30	22.40	
2	11.70	10.30	11.10	14.80	26.60	
3	20.70	10.00	0.20	11.60	15.40	
4	19.70	12.20	5.00	18.00	26.60	
5	15.50	9.10	17.80	14.20	26.90	
6	23.00	23.30	17.60	27.10	7.00	
7	16.90	9.60	4.70	24.70	26.30	
8	7.10	22.60	24.70	22.40	9.00	
9	15.20	25.90	15.80	18.10	9.70	
10	6.50	20.90	24.90	17.30	18.00	
11	20.90	19.70	11.20	24.70	8.70	
12	16.20	17.80	5.00	21.60	18.10	
13	8.40	17.30	21.30	15.10	25.40	
14	18.00	17.70	0.30	22.10	25.60	
15	1.00	24.80	21.20	18.40	27.90	
Avg =		14.78	12.36	19.49	19.57	
Std Dev =		6.47	8.70	4.48	7.81	
Variance =		41.92	75.71	20.10	60.92	
F =		1.45	1.24	3.03		
No. of readings						
> 30.5 microns		2	2	0	0	

Surface Measurements (microns)

Stone I - marble		CaCl ₂ O ₂	Ba(OH) ₂	NaOCl	H ₂ O ₂	Control
1		21.70	23.90	15.20	30.40	15.20
2		20.20	24.50	23.20	20.40	20.10
3		28.70	26.30	22.50	22.20	26.10
4		27.20	17.40	22.10	15.40	22.30
5		23.40	15.70	23.10	12.70	15.00
6		14.30	22.90	26.40	16.40	20.00
7		16.50	11.60	11.60	6.80	23.20
8		22.60	26.90	20.40	18.90	14.60
9		5.90	24.40	18.60	19.70	17.60
10		30.10	13.80	19.70	19.70	21.90
11		20.60	5.90	6.70	13.70	23.60
12		12.90	10.80	19.80	29.60	25.40
13		19.20	21.60	25.60	16.70	11.40
14		26.50	18.50	18.30	18.00	22.00
15		22.20	22.50	24.10	22.40	19.30
Avg =		20.80	19.12	19.82	18.87	19.85
Std Dev =		6.45	6.37	5.31	6.03	4.31
Variance =		41.66	40.53	28.20	36.39	18.54
F =		2.25	2.19	1.52	1.96	
No. of readings =						
> 30.5 microns		4	2	2	2	1

Surface Measurements (microns)

Stone J - granite		CaCl ₂ O ₂	Ba(OH) ₂	NaOCl	H ₂ O ₂	Control
	1	13.10	18.20			22.90
	2	24.60	20.60		unable to take	12.80
	3	27.20	12.00		surface readings	14.90
	4	20.10	19.80		due to extreme	19.90
	5	21.90	9.90		variations in	28.40
	6	19.00	17.50		surface	15.50
	7	21.00	14.70		texture	18.90
	8	23.90	14.50			14.20
	9	22.00	19.60			11.90
	10	22.60	26.90			19.40
	11	12.80	16.60			16.80
	12	13.90	12.60			26.60
	13	15.70	12.90			21.50
	14	16.80	20.90			26.50
	15	18.60	9.70			13.10
Avg =		19.55	16.43			18.89
Std Dev =		4.38	4.58			5.38
Variance =		19.20	20.94			28.94
F =		1.51	1.38			
No. of readings						
> 30.5 microns		0	2			2

Surface Measurements (microns)

Stone K - sandstone		CaCl ₂ O ₂	Ba(OH) ₂	NaOCl	H ₂ O ₂	Control
1	18.90	21.50	16.60	12.10		
2	12.50	16.20	25.80	13.20		
3	18.80	7.90	24.60	13.90		
4	6.90	3.30	15.80	18.00		
5	17.70	13.40	12.70	9.30		
6	9.40	4.00	11.20	10.80		
7	25.40	9.80	9.00	20.00		
8	25.80	20.30	30.20	24.30		
9	7.40	20.10	12.20	16.60		
10	10.40	8.60	20.50	19.20		
11	13.60	6.40	14.50	14.60		
12	25.10	19.50	12.80	8.40		
13	17.20	18.50	15.70	18.00		
14	20.70	8.50	28.50	13.00		
15	22.30	22.60	17.51	15.73		
Avg =	16.81	13.37	6.52	4.96		
Std Dev =	6.49	6.78	42.55	24.61		
Variance =	42.11	45.96	1.73			
F =	1.71	1.87				
No. of readings						
> 30.5 microns	1	0	2	0		

Micro-Drop Test (seconds)

First Poulticing								
Stone E - marble		CaCl ₂ O ₂	Ba(OH) ₂	NaOCl	H ₂ O ₂	Control		
Drop # 1		12.05	2.45	5.50	8.30	2.00		
2		15.55	4.10	1.55	6.25	1.60		
3		12.55	5.20	3.40	6.10	2.10		
4		16.30	2.40	5.15	8.30	1.15		
5		8.60	4.20	2.45	2.50	2.25		
6		5.10	13.30	2.35	5.15	0.50		
7		3.40	5.40	3.10	2.60	1.00		
8		4.55	2.55	4.00	5.55	1.15		
9		9.35	3.55	5.30	7.14	2.25		
10		8.40	4.55	2.60	3.50	2.40		
11		3.40	2.15	5.30	4.55	1.10		
12		4.60	1.50	6.10	5.30	2.45		
13		5.35	3.60	2.40	8.40	3.40		
14		5.00	6.00	2.00	4.50	1.60		
15		8.20	5.50	3.50	8.10	3.25		
Avg =		8.16	4.43	3.65	5.75	1.88		
Std Dev=		4.27	2.81	1.48	2.02	0.83		
Variance =		18.23	7.92	2.18	4.07	0.69		
F =		26.50	11.51	3.17	5.92			

Calculated F values are compared to a tabulated F value of 2.40 for 14 degrees of freedom, at a 95% Confidence Level.

Micro-Drop Test (seconds)

Second Poulticing						
Stone E - marble						
	CaCl2O2	Ba(OH)2	NaOCl	H2O2	Control	
Drop # 1	10.20	2.50	4.45	15.35	2.25	
2	17.10	4.35	5.30	36.20	2.20	
3	10.25	10.35	8.30	27.50	1.25	
4	22.00	3.35	4.00	10.25	3.40	
5	15.00	5.40	5.15	14.00	2.00	
6	12.15	6.05	6.55	6.00	7.25	
7	7.25	8.45	3.45	21.40	4.20	
8	17.20	8.55	3.05	12.35	1.45	
9	7.45	4.05	8.25	14.35	2.25	
10	5.20	9.10	5.35	2.20	3.20	
11	14.10	4.25	5.05	26.30	4.40	
12	16.10	8.55	6.30	11.45	2.45	
13	14.00	6.20	5.20	19.50	2.15	
14	14.05	7.45	3.55	17.60	2.05	
15	15.00	5.50	5.50	14.20	2.15	
Avg =		13.14	5.30	16.58	2.84	
Std Dev=		4.45	1.57	8.67	1.52	
Variance =		19.78	2.45	75.23	2.30	
=		8.61	1.07	32.74		

Calculated F values are compared to a tabulated F value of 2.40 for 14 degrees of freedom, at a 95% Confidence Level

Micro-Drop Test (seconds)

First Poulticing	CaCl ₂ O ₂	Ba(OH) ₂	NaOCl	H ₂ O ₂	Control
Stone F - marble					
Drop # 1	2.40	25.10	5.55	10.25	10.15
2	4.05	6.00	6.00	7.20	7.55
3	2.45	23.00	8.35	8.40	9.10
4	7.10	47.00	7.50	6.50	1.45
5	1.20	21.40	4.15	5.10	8.10
6	4.05	6.55	9.25	16.40	20.40
7	9.45	17.20	7.55	5.25	7.00
8	5.10	6.20	11.50	7.10	4.05
9	3.10	9.55	2.15	7.40	14.10
10	10.00	16.15	8.45	3.40	5.50
11	2.15	4.00	4.35	7.30	14.60
12	3.35	7.10	5.20	8.40	3.25
13	7.20	4.55	6.10	6.30	4.15
14	2.00	36.15	10.05	10.40	3.35
15	6.30	23.05	6.10	6.00	3.25
Avg =	4.66	16.87	6.82	7.69	7.73
Std Dev=	2.76	12.67	2.47	3.03	5.26
Variance =	7.64	160.65	6.09	9.20	27.63
F =	3.62	5.81	4.54	3.00	

Calculated F values are compared to a tabulated F value of 2.40 for 14 degrees of freedom, at a 95% Confidence Level.

Micro-Drop Test (seconds)

Second Poulticing		CaCl2O2	Ba(OH)2	NaOCl	H2O2	Control
Stone F - marble						
Drop # 1		4.40	17.00	15.00	21.00	3.35
2		4.40	8.25	18.15	13.35	5.20
3		3.00	15.35	4.15	4.08	9.30
4		5.00	25.10	4.15	21.45	15.40
5		12.20	18.50	10.40	20.05	9.50
6		6.05	16.10	5.25	39.00	4.40
7		13.05	19.40	11.55	26.50	4.00
8		5.00	18.20	4.55	11.45	5.30
9		6.50	13.10	4.50	19.05	2.50
10		8.55	30.10	4.10	19.10	3.55
11		19.30	11.45	4.45	22.00	7.40
12		3.30	18.00	4.55	6.15	8.05
13		4.50	13.20	4.55	24.25	4.15
14		7.05	15.10	5.25	25.00	6.50
15		6.40	13.20	5.45	20.05	9.20
Avg =		7.25	16.80	7.07	19.50	6.52
Std Dev=		4.44	5.38	4.51	8.51	0.00
Variance =		19.67	28.98	20.32	72.43	11.46
F =		1.72	2.53	1.77	6.32	

Micro-Drop Test (seconds)

First Polishing Stone I - marble	CaCl ₂ O ₂	Ba(OH) ₂	NaOCl	H ₂ O ₂	Control
Drop # 1	1.55	4.00	1.50	1.00	4.00
2	1.45	7.40	4.05	0.60	3.20
3	3.45	1.05	2.55	0.40	4.60
4	3.40	3.35	3.05	0.40	4.55
5	5.00	2.10	2.05	1.35	4.30
6	5.05	13.05	3.40	1.30	6.40
7	5.10	1.50	3.40	1.35	2.10
8	6.40	1.00	4.10	1.20	3.10
9	3.10	4.10	1.55	2.20	5.10
10	1.00	3.30	2.20	1.35	2.20
11	6.15	6.20	2.55	1.15	5.30
12	2.55	4.50	2.05	1.00	5.50
13	2.15	2.30	3.55	1.55	2.15
14	1.05	2.55	5.05	1.00	3.15
15	2.10	1.50	2.30	2.10	4.20
Avg =	3.30	3.86	2.89	1.20	3.99
Std Dev=	1.84	3.14	1.02	0.52	0.00
Variance =	3.37	9.86	1.05	0.27	1.72
F =	1.95	5.71	1.65	6.40	

Micro-Drop Test (seconds)

Second Potting Stone I - marble		CaCl ₂ O ₂	Ba(OH) ₂	NaOCl	H ₂ O ₂	Control
Drop # 1		4.20	3.50	1.30	1.10	3.00
2		2.00	12.40	1.05	1.05	1.00
3		2.35	6.00	1.15	0.45	1.45
4		2.15	2.00	1.00	1.00	1.45
5		1.50	6.00	0.50	1.00	3.30
6		2.05	6.35	1.20	0.55	2.40
7		1.55	5.20	1.40	1.00	2.05
8		2.15	6.50	0.50	0.50	1.00
9		1.50	7.15	1.00	0.45	2.00
10		2.30	9.20	1.15	1.05	1.50
11		3.05	2.40	2.20	0.55	1.15
12		2.40	4.20	1.30	0.50	1.40
13		3.00	6.20	1.00	1.05	1.25
14		2.10	5.15	1.10	1.10	2.00
15		1.50	5.05	1.50	1.00	1.05
Avg =		2.25	5.82	1.16	0.82	1.73
Std Dev=		0.73	2.58	0.40	0.28	0.00
Variance =		0.53	6.65	0.16	0.08	0.51
F =		1.02	12.96	3.18	6.72	

Calculated F values are compared to a tabulated F value of 2.40 for 14 degrees of freedom, at a 95% Confidence Level.

Micro-Drop Analysis of Variance

Stone E - marble			
First Poulting		Second Poulting	
SR =	463.22	SR =	1474.77
SR ² =	6.62	SR ² =	21.07
ST =	332.71	ST =	2001.29
ST ² =	83.18	ST ² =	500.32
ST ² /SR ² =	12.57	ST ² /SR ² =	23.75
Stone F - marble			
First Poulting		Second Poulting	
SR =	2957.05	SR =	2139.98
SR ² =	42.24	SR ² =	30.57
ST =	1327.44	ST =	2318.91
ST ² =	331.86	ST ² =	579.73
ST ² /SR ² =	7.86	ST ² /SR ² =	18.96
Stone I - marble			
First Poulting		Second Poulting	
SR =	227.72	SR =	111.04
SR ² =	3.25	SR ² =	1.59
ST =	75.94	ST =	242.78
ST ² =	18.98	ST ² =	60.69
ST ² /SR ² =	5.84	ST ² /SR ² =	38.26

Sample Weights (grams)

	Initial Weight	Dry Weight	Residual Moisture	Weight after Treatment	Treatment Residue
Sample A - Ba(OH)2	Marble	145.52	145.50	145.67	0.17
	Sandstone	171.96	169.64	171.12	1.48
Sample B - NaOCl	Marble	132.22	132.21	132.26	0.05
	Sandstone	144.62	141.82	141.86	0.04
Sample C - CaCl2O2	Marble	147.31	147.30	147.34	0.04
	Sandstone	155.36	153.47	153.55	0.08
Sample D - H2O2	Marble	127.20	127.18	127.19	0.01
	Sandstone	178.34	176.12	176.06	-0.06
Sample E - Control	Marble	145.48	145.52	145.46	
	Sandstone	132.47	130.75	130.71	

Hygroscopicity

100% RH Weights (grams) - 1st Run					100% RH Percent Increase - 1st Run						
	Start	Week 1	Week 2	Week 3	Week 4		Start	Week 1	Week 2	Week 3	Week 4
Sample A - Ba(OH) ₂											
Marble	145.61	145.97	145.95	145.82	145.81	Marble	0	0.25	0.23	0.14	0.14
Sandstone	171.08	173.6	174.63	174.96	174.3	Sandstone	0	1.47	2.08	2.27	1.88
Sample B - NaOCl											
Marble	132.20	132.33	132.33	132.29	132.28	Marble	0	0.10	0.10	0.07	0.06
Sandstone	141.82	143.09	143.34	143.10	142.88	Sandstone	0	0.90	1.07	0.90	0.75
Sample C - CaCl ₂ O ₂											
Marble	147.28	147.42	147.43	147.36	147.37	Marble	0	0.10	0.10	0.05	0.06
Sandstone	153.51	154.85	155.07	154.81	154.50	Sandstone	0	0.87	1.02	0.85	0.64
Sample D - H ₂ O ₂											
Marble	127.13	127.2	127.21	127.17	127.18	Marble	0	0.06	0.06	0.03	0.04
Sandstone	176.02	176.98	177.05	176.87	176.71	Sandstone	0	0.55	0.59	0.48	0.39
Sample E - Control											
Marble	145.46	145.54	145.52	145.48	145.51	Marble	0	0.05	0.04	0.01	0.03
Sandstone	130.71	131.28	131.32	131.19	131.12	Sandstone	0	0.44	0.47	0.37	0.31

Conductivity Measurements (mS/cm)

Sample	Conductivity (mS/cm)				Average	Treatment Residue (cg)
	0.41	0.44	0.43	0.41		
Sample A - Ba(OH) ₂ Marble Sandstone	0.45	0.46	0.45	0.46	0.43	17
					0.45	148
Sample B - NaOCl Marble Sandstone	0.39	0.44	0.44	0.43	0.42	5
	0.47	0.46	0.47	0.48	0.47	4
Sample C - CaCl ₂ O ₂ Marble Sandstone	0.44	0.46	0.44	0.44	0.45	4
	0.47	0.47	0.49	0.48	0.47	8
Sample D - H ₂ O ₂ Marble Sandstone	0.43	0.45	0.43	0.44	0.45	1
	0.47	0.46	0.49	0.47	0.47	-6
Sample E - Control Marble Sandstone	0.40	0.43	0.43	0.42	0.42	
	0.47	0.48	0.47	0.46	0.47	
Deionized H ₂ O	0.01	0.01	0.01	0.01	0.01	

Hygroscopicity

100% RH Weights (grams) - 2nd Run				100% RH Percent Increase - 2nd Run			
	Start	Week 1	Week 2	Week 3	Week 4		
Sample A - Ba(OH)₂							
Marble	145.54	145.57	145.55	145.55	145.55	0	0.01
Sandstone	170.67	172.35	172.57	172.68	172.51	0	1.11
Sample B - NaOCl							
Marble	132.20	132.23	132.21	132.21	132.22	0	0.01
Sandstone	141.82	142.71	142.62	142.68	142.69	0	0.61
Sample C - CaCl₂O₂							
Marble	147.29	147.32	147.3	147.3	147.31	0	0.01
Sandstone	153.52	154.43	154.32	154.41	154.50	0	0.58
Sample D - H₂O₂							
Marble	127.13	127.15	127.13	127.13	127.14	0	0.01
Sandstone	176.04	176.84	176.71	176.79	176.78	0	0.43
Sample E - Control							
Marble	145.47	145.51	145.48	145.48	145.48	0	0.01
Sandstone	130.76	131.26	131.20	131.23	131.21	0	0.36

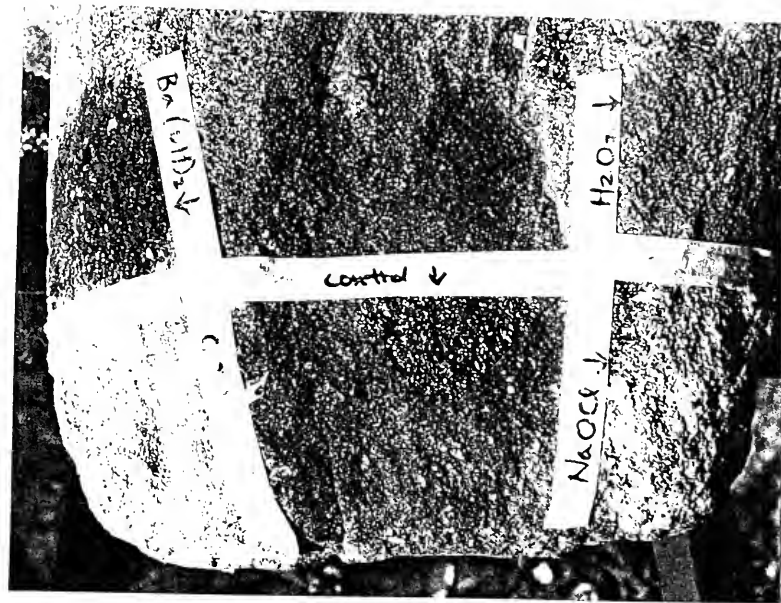


Figure G-1. Stone J - granite (left) and stone K - sandstone (right) after treatment.

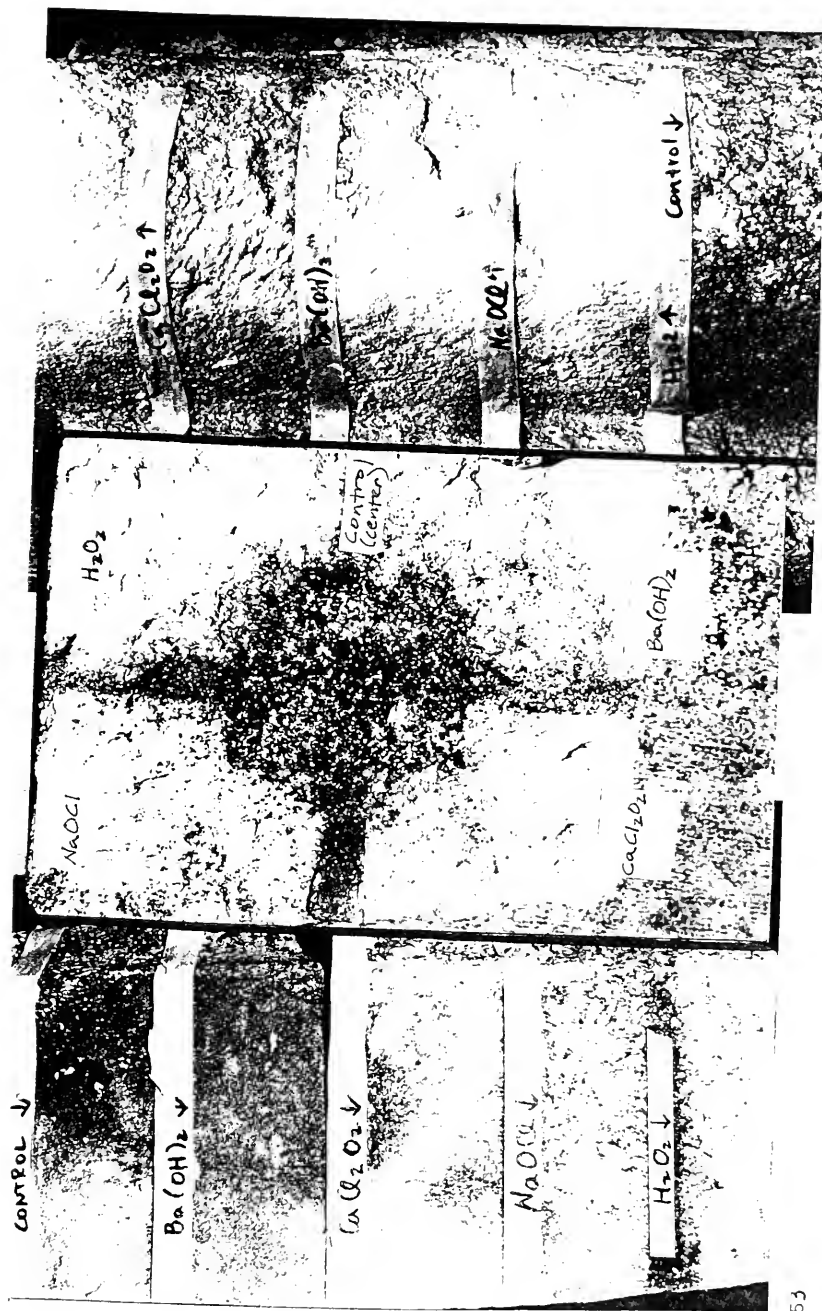


Figure G-2. Stone E (left), stone F (center), and stone I (right) after treatment.

Index

algae 15-25, 27, 33, 47

barium hydroxide 34, 37, 42, 44, 47, 52, 55, 56, 59, 64, 69, 71, 73, 74

calcium hypochlorite 32, 33, 42, 43, 50, 55, 59, 63, 64, 71

Cliveden 2, 3, 5-9, 11, 12, 20, 21, 29, 70, 71

fungi 17, 18, 20, 21, 23, 25-30, 35, 36

hydrogen peroxide 32, 33, 44, 48, 52, 55, 59, 63, 67, 71, 73

lichen 17, 18, 20, 21, 23, 25, 26-30, 35, 36

microclimate 14, 16, 20, 70

sodium hypochlorite 32, 33, 42, 50, 59, 63, 64, 71

Anne & Jerome Fisher

FINE ARTS LIBRARY

University of Pennsylvania

Please return this book as soon as you have finished with it. It must be returned by the latest date stamped below.



FISHER
FINE ARTS LIBRARY

FEB 18 1998

UNIV. OF PENNA

N/1198/04975/9637X

3 1198 04975 9637



N/1198/04975/9637X